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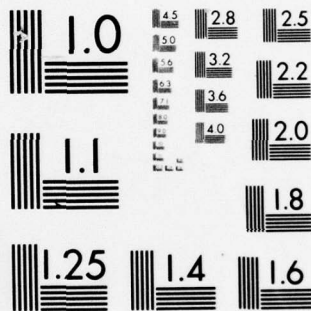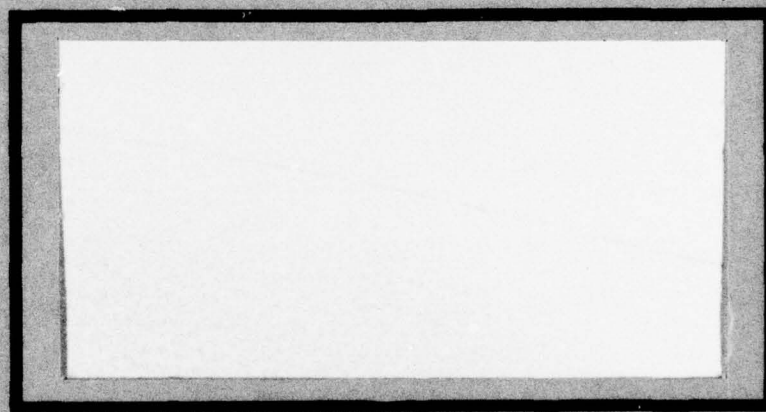
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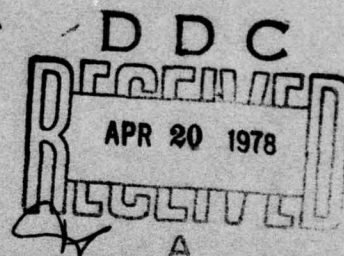END
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Wright-Patterson Air Force Base, Ohio

LONG PATH, VISIBLE AND INFRARED
TRANSMISSOMETER: CALIBRATION AND USE

THESIS

AFIT/GEP/77-14   LEO O. VROOMBOUT
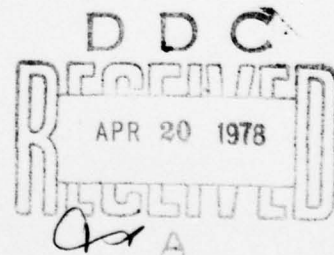
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LONG PATH, VISIBLE AND INFRARED

TRANSMISSOMETER: CALIBRATION AND USE

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

Leo O. Vroombout

Graduate Engineering Physics

October 1977

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Leo O. Vroombout

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Abstract

The Barnes Model 14-WP transmissometer is one of the principle optical path calibration instruments of the Air Force Avionics Laboratory's Targeting Systems Characterization Facility. A simple test based on LOWTRAN IIIB was devised to certify system calibration while installed on an eight kilo-meter optical path. In addition, an optical path anomaly was investigated. Results are discussed and recommendations for additional calibration tests and new procedures are made.

LONG PATH, VISIBLE AND INFRARED

TRANSMISSOMETER: CALIBRATION AND USE

I. Introduction

Background

During the war in Southeast Asia, it became more ob-
vious than ever before that our forces must have the ability
to prevent the enemy from taking advantage of darkness and
adverse weather to move troops and supplies. One of the more
successful sensors to be developed to satisfy this require-
ment was the Forward Looking Infrared set (FLIR). Although
the FLIR concept had been demonstrated in the mid- 1950's,
the electronics technology was not sufficiently developed to
permit developing a useful, airborne FLIR until 1965 when the
first exploratory development FLIR was tested in Southeast
Asia. From then until 1974, over sixty different types of
FLIR's were developed and several hundred were produced (Ref
11:5).

Throughout this period, the emphasis was on improving
infrared (IR) detectors as well as the associated signal pro-
cessing electronics and optics. However, by the end of this
period, as cost increases began to exceed performance in-
creases, the emphasis shifted toward better understanding of
the physics of thermal imaging. Such improved understanding
lead to computer modeling of the FLIR and its military appli-

cation. These models are intended to determine the extent to which FLIR performance must imporve, if at all, in order to satisfy future military requirements. For instance, a major question to be answered prior to developing the next generation Air Force FLIR is what is the optimum spectral window for its operation? Does it fall within the 3 to 5 or 8 to 12 micrometer atmospheric windows? The models should answer this question. Unfortunately, there is little confidence in certain parts of the models; two particularly poor areas involve atmospheric propagation under very low visibility conditions and dynamic (search) modeling (Ref 23:2). This thesis will address the atmospheric propagation issue.

Atmospheric Transmission. The importance of atmospheric effects on the IR energy emitted by a target and received by a FLIR is well documented (Refs 1; 11:30-52; 12; 15; 22:10-16; 23: chap 3; 25: chap 6). The most important effects are (1) attenuation of the target energy by molecular absorption and by scattering out of the path, (2) scattering of background energy into the path, (3) the IR radiance of the air mass in the path, and (4) optical turbulence along the path.

The first three effects have been under study both in the laboratory and in the field since the late 1950's. In fact, in 1957, T. L. Altshuler (Ref 4) published a set of curves which may be used with reasonable confidence whenever the total transmission is greater than 20 percent. More recently, the laboratory and field data have been complied and made available in the Air Force Geophysics Laboratory

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computer program LOWTRAN (Refs 13; 17; 18; 19). It is
generally agreed that the most recent version of LOWTRAN,
LOWTRAN IIIB (Ref 19), provides quite accurate transmission
values when the total path transmission is greater than 10
per cent and scattering losses are low (Ref 23:1-13); however,
when scattering losses are high, LOWTRAN departs from measured
data by as much as a factor of three (Ref 16).

The fourth effect, optical turbulence, is the subject
of current research (Refs 1; 2:31-35). As a result, only
quasi-empirical mathematical models are available for engi-
neering estimates of the degradation due to optical turbu-
lence; these estimates do agree favorably with the limited
experimental data that exist at this time (Ref 2:4).

This thesis will be concerned primarily with the first
effect, attenuation by absorption and scattering. An overview
of atmospheric transmission theory is provided in chapter II.
Appendix A contains a computer listing of the modified LOWTRAN
program developed for this thesis.

Atmospherics Effects Measurement Program. Because of
the need to validate electro-optical sensor mathematical mo-
dels and because of the lack of reliable atmospheric trans-
mission data (Ref 11:31), particularly under low transmission/
high scattering conditions, the Air Force Avionics Laboratory
(AFAL) has established an Atmospheric Effects Measurement
Program within its Targeting Systems Characterization Facility.
This facility consists of electro-optical imaging sensors,
including FLIR's, and test equipment, targets and mete-

orological instrumentation. The intent is to provide a fully
characterized, eight kilometer, optical path between the sen-
sors and the targets. To accomplish this, standard meteor-
ological instruments as well as aerosol particle counting and
sizing instruments are located at the zero, four and eight
kilometer positions along the optical path. In addition, a
Barnes Model 14-WP transmissometer (0.5 to 14 micrometers) is
located so as to measure the spectral transmission along the
eight kilometer path. The data from the transmissometer and
the other instrumentation will provide the optical path cal-
ibration and will also be available to validate or to provide
corrections to LOWTRAN. In the latter case, the transmisso-
meter is the most important instrument; its calibration is
one of the first tasks in the Atmospheric Effects Program and
is the primary concern of this thesis. A summary of trans-
missometer theory is contained in chapter III.

Transmissometer Calibration. An IR transmissometer
consists of a standard source of thermal radiation and a
projector for that energy (somewhat like a searchlight) and
a receiver that collects the energy after it has been atten-
uated by the atmosphere. The receiver electronics then con-
vert the energy into a recordable output.

No standard procedure exists for calibrating a trans-
missometer; however, those procedures that do exist have sev-
eral features in common. The receiver is first set up in the
laboratory looking into its own source or at another black-
body reference source. The electronics are then adjusted so

that a known relationship exists between this measurement and, based upon geometric arguments, that which would be expected on the test range. Then the transmissometer is installed and, if possible, some simple test is devised to verify the calibration *in situ*. This test usually consists of comparing the measured data to LOWTRAN predictions during periods of high transmission with low scattering (Refs 7:7).

In addition to transmissometer theory, chapter III also contains a description of the Barnes Model 14-WP transmissometer and of its installation in the AFAL Targeting Systems Characterization Facility. Chapter IV contains a description of the experiments performed with the transmissometer and the results. Chapter V contains a summary of the work under this thesis and recommendations for additional calibration testing. Appendix B is a draft calibration handbook for the transmissometer.

Objectives

The objectives of the work described on this thesis were as follows:

a. develop an understanding of the principles of operation of the transmissometer,

b. devise a simple test to verify the transmissometer calibration while installed on the eight kilometer range,

c. identify those areas which require additional calibration testing,

d. conduct the initial transmission measurements

prior to the transmissometer's being interfaced with the facility's automatic data processing equipment.

The last objective was not fulfilled partly because of equipment malfunction and partly because of visibilities that were too low to permit alignment and calibration.

II. Atmospheric Effects

The atmosphere is important to all living creatures on this world not only because of the gases that are breathed and the rain and heat retention that are provided but also because of the protection from harmful solar radiation. None of these things could be provided if the atmosphere did not absorb electromagnetic radiation. As desirable as this feature is, it is undesirable to people or sensors that need to see through the atmosphere for long distances. Consequently, it is necessary to identify and quantify the atmospheric effects on electromagnetic radiation so that they at least might be corrected for. This chapter provides an overview of atmospheric attenuation mechanisms, a brief description of the most commonly accepted atmospheric transmission model and a brief description of a modification that was accomplished on that model for this thesis. Samples of the output of the model are included in the fourth chapter.

Atmospheric Attenuation Mechanisms

As it propagates through the atmosphere, visible and infrared radiation are selectively absorbed by several atmospheric gases and scattered away from the direction of propagation by aerosol particles suspended in the atmosphere. Excellent summaries of these effects have been written by Hudson (Ref 9: chap. 4). Lloyd (Ref 11: chap. 2), and Wolfe (Ref 25: chap. 6). Middleton (Ref 15) has written an excellent reference text on seeing through the atmosphere and McCartney (Ref 12) has

discussed the scattering processes in great detail. The fol-
lowing discussion is drawn primarily from these sources.

The general process of attenuation of radiation as it
passes through the atmosphere is called extinction. For mono-
chromatic radiation, the transmittance along a path may be
expressed by the Lambert-Beer law

$$T = \exp(-\sigma R) \tag{1}$$

where T is the transmittance, σ is the extinction coef-
ficient and R is the length of the path. The extinction
coefficient may be further separated into

$$\sigma = a + \gamma \tag{2}$$

where a is the absorption coefficient and γ is the scat-
tering coefficient; both of these coefficients vary with
wavelength. Absorption is primarily a function of molecular
excitation and affects the infrared more than the visible
spectral region. On the other hand, scattering is a function
of particle size and, under most weather conditions, can cause
greater attenuation in the visible than in the IR.

Visible and Near-IR Spectral Region. Extinction in
this region is primarily caused by scattering by gas mole-
cules (Rayleigh scattering) and haze (Mie scattering); how-
ever, water vapor molecular absorption does become important
in the near-IR region. Energy scattered out of the path and
then back again could also have an effect on transmission
measurements. Such an effect should be very small if the

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transmissometer receiver has a very small field of view.
Stewart and Curcio (Ref 20:804) derived an equation for
this effect

$$T_\theta = T + 0.5(1-T)(1-e^{-\theta}) \qquad (3)$$

where T_θ is the transmittance measured by an instrument having
a field of view of θ radians and T is the transmittance that
would have been measured in the absence of scattered light.
For fields of view smaller than one degree, T_θ and T are
the same except under conditions of very low transmission;
i.e., less than three per cent.

Far-IR Spectral Region. Extinction in this region is
primarily caused by molecular absorption. The most important
absorbers are water vapor and carbon dioxide. Water vapor has
both a discrete and a continuum absorption in this region.
The latter is not well understood but has been measured.
Scattering becomes the dominant extinction mechanism only for
low visibility or for low temperature, low absolute humidity
conditions.

Middle-IR Spectral Region. Extinction is this region
is caused by both molecular absorption and scattering; however,
there are discrete spectral regions (around 2.2 and 3.8 micro-
meters) in which transmission through haze is better than in
the visible and transmission through water vapor is better than
in the far-IR (Ref 2:6).

LOWTRAN IIIB

Because of the widely varying value of the extinction
coefficient as a function of wavelength and even more so as a

function of atmospheric conditions (Pressure, temperature and absolute humidity), many attempts have been made to develop useable models for estimating atmospheric transmittance. Altshuler wrote one of the best early models (Ref 4); however, it was too cumbersome because of the use of scaled graphs. McClatchey et al, of the Air Force Geophysics Laboratory (formerly the Air Force Cambridge Research Laboratory), followed Altshuler's approach, added a lot of curve fitted empirical data (both laboratory and field measurements) and developed a very flexible computer model, which in its latest version, is called LOWTRAN IIIB (Ref 19). The code permits calculating atmospheric transmittance in the spectral region from 0.25 to 28.5 micrometers along arbitrary, slant paths. Any one of six standard atmospheric models may be used or meteorological or radiosonde data may be inserted. Five different aerosol models are also available; however, only the maritime model is said to compare favorably with measurements over the European continent during conditions of low visibility (Ref 16). In the absence of aerosol scattering, LOWTRANS's accuracy is stated to be within a few per cent (Ref 7).

LOWTRAN predicts atmospheric transmission by calculating the attenuation for each of the following contributors:

    a. water vapor line absorption ($350-14500 cm^{-1}$)

    b. uniformly mixed gases (CO_2, N_2O, CH_4, CO, N_2, and O_2) line absorption ($500-8060$ and $12970-13190$ cm^{-1})

    c. ozone line absorption ($575-3270$ cm^{-1})

    d. nitrogen continuum ($2080-2740$ cm^{-1})

      e.   water vapor continuum (670-1400 cm^{-1})

      f.   molecular scattering (2740-40000 cm^{-1})

      g.   aerosol scattering and absorption (350-40000 cm^{-1})

      h.   ozone absorption (13000-23400 cm^{-1})

The total transmittance for a 20 cm^{-1} frequency interval is then obtained by multiplying the individual transmittances obtained from the above attenuations. This procedure is repeated throughout the spectral region of interest in increments of 5 cm^{-1} or greater, as specified by the user. This approach has been shown to be valid for transmissions greater than about 30 per cent (Ref 23:24) and is probably valid down to about 10 per cent (Ref 23:1-14) provided that aerosol scattering is not the primary loss mechanism. Very little experimental data exists with which to correct or to validate LOWTRAN under low transmission/high scattering conditions.

Modified LOWTRAN IIIB

A substantial portion of the LOWTRAN IIIB program is concerned with computing transmission along slant paths. Since the optical path for this thesis is practically horizontal, these cards were removed. In order to increase the program's flexibility, several DO loops were added to permit iterating the temperature, dew point and visibility and plotting transmission as a function of the iterated variable or as a function of wavelength. A source listing is contained in appendix A.

III. The Transmissometer

As mentioned in the first chapter, a transmissometer consists of a standard radiation source, a projector for that radiation and a receiver that collects the radiation after it has propagated through the atmosphere. This chapter provides a general description of an IR transmissometer, a brief description of the theory of its operation and a specific description of the transmissometer used for the work reported in this thesis, the Barnes Model 14-WP, and of its installation and calibration in the AFAL Targeting Systems Characterization Facility.

General Description

An IR transmissometer uses a high temperature black body as the source of its radiation. The source is usually maintained at a constant temperature by constant current electronics and its own thermal inertia. The radiation from the source floods an aperture which is located at the focal plane af the projector. In order to provide background discrimination, the energy is usually chopped at 1000Hz or more just in front of the aperture.

The projector is best compared to a searchlight, although, in essence, it is a collimator. The energy entering the aperture is collected by an off-axis paraboloid or by an on-axis paraboloid in a Newtonian configuration. The energy is then projected into the atmosphere in a highly collimated beam; the smaller the aperture, the greater the collimation.

For a true point source, the beam would be perfectly colli-
mated.

After propagation through the atmosphere over a speci-
fied range, the beam is incident upon the receiver. The re-
ceiver optics, usually Cassegrainean, then focus the radiation
upon a detector which is sensitive to IR energy in the wave-
length region of interest. The wavelength region is normally
defined by inserting a spectral filter in the optical path
in front of the detector. The detector converts the IR energy
into an electrical signal which is amplified and processed and
then presented to the experimenter either as an irradiance
value or as a transmission value. In the latter case, the
transmission is defined to be the ratio of the IR energy act-
ually collected to that IR energy which would have been col-
lected if there were no intervening atmosphere. The next
section details the procedure for calculating the energy that
would have been collected in the absence of an atmosphere.

Theory

One of the most comprehensive articles on beam pro-
jectors was written by Frank Benford in 1945 (Ref 5). Unfor-
tunately, this article was only concerned with aspheric op-
tics (the transmissometer used for this work had a spherical
mirror). Klein (Ref 10:136-138) provides a reasonably detailed
description of a searchlight using a spherical mirror as does
Hudson (Ref 9:227-228). The following discussion is drawn
from these sources.

Figure 1 shows a single mirror collimator/searchlight
(source size and angles are exaggerated for clarity). The
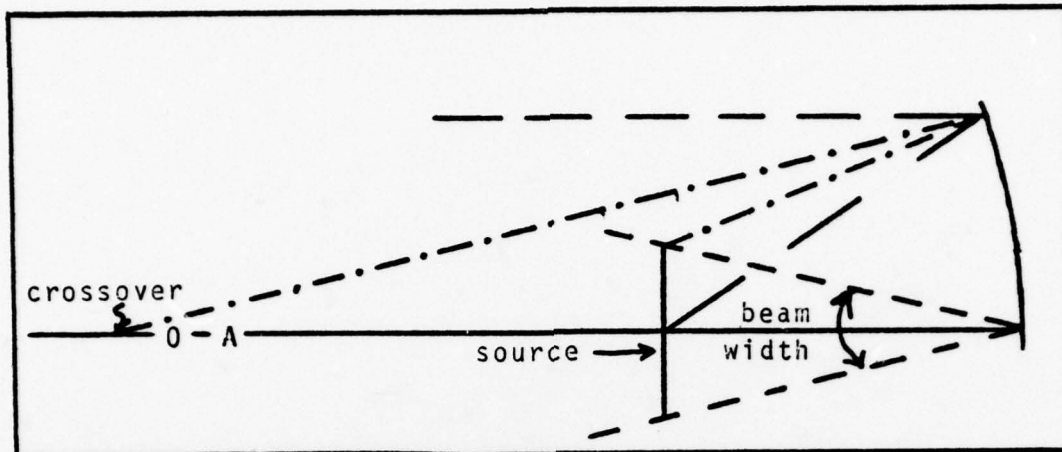
Fig. 1. Searchlight Ray Trace

limiting rays are depicted for bundles originating at the
center and at one edge of the source. The angular beamwidth
is equal to the ratio of the size of the source to the focal
length of the mirror. The irradiance in the beam is indepen-
dent of the distance from the mirror at all points in the
central cone to the right of the crossover point. This occurs
when the field point is close enough that the source aperture
is the aperture stop. Beyond the crossover point, the
irradiance in the beam falls off inversely with the square of
the distance from the mirror provided that the field point is
still in the central cone. In this case, the mirror is the
aperture stop and increasing the source aperture size does
not change the irradiance at the field point, only the beam
diameter. The equations governing the irradiance at a field
point in the central cone are, from Klein (Ref 10:137)

$$E_{near} = L\pi r_s^2 / f^2 \quad , \quad D < R_1 f / r_s \qquad (4)$$

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$$E_{far} = L\pi R_1^2 / D^2 \quad , \quad D \geq R_1 f / r_s \qquad (5)$$

where

E = irradiance (before or after crossover)
L = radiance of the source
r_s = radius of the source aperture
f = focal length of the mirror
R_1 = radius of the mirror
D = distance to the field point

Note that the distance from the mirror to the crossover point is $R_1 f / r_s$ and that the beam angular width is $2R_s/f$. All of these equations are small angle approximations; this is justifiable since the angles involved typically range from a fraction to a few milliradians.

In practice, a source aperture should be selected such that the central cone diameter at the field point is large enough to compensate for beam wander induced by atmospheric turbulence/scintillation. Also, a very much smaller aperture, R_{cal} ,should be selected for calibrating the receiver at zero range. This assures that the receiver electronics are not saturated as well as that the receiver is precisely aligned with the beam projector's optical axis. Then, using equations (4) and (5), the ratio of the calibration irradiance to the irradiance at the field point in the absence of the atmosphere is

$$\text{cal factor} = (R_{cal} D / R_1 f)^2 \qquad (6)$$

Barnes Model 14-WP Transmissometer

Transmitter Assembly. The beam projector of the trans-

missometer used for this thesis consists of a Newtonian tele-
scope, a Barnes 1000°C black body source and a tungsten foil
2820°K color temperature visible light source. Figure 2 is a
layout drawing of these components. The radiation from the
two sources is combined by a germanium beam splitter and is
chopped by a gold plated mechanical chopper (1180Hz) prior
to illuminating the aperture plate. The aperture plate is
located at the focus of the telescope mirror and contains
eight apertures ranging in size from 0.0048 inches in diameter
(CAL) to 0.2560 inches in diameter. The telescope mirror has
a focal length of 49.5 inches. Its diameter is 16.5 inches,
but, allowing for obscuration, the effective diameter is
14.95 inches.
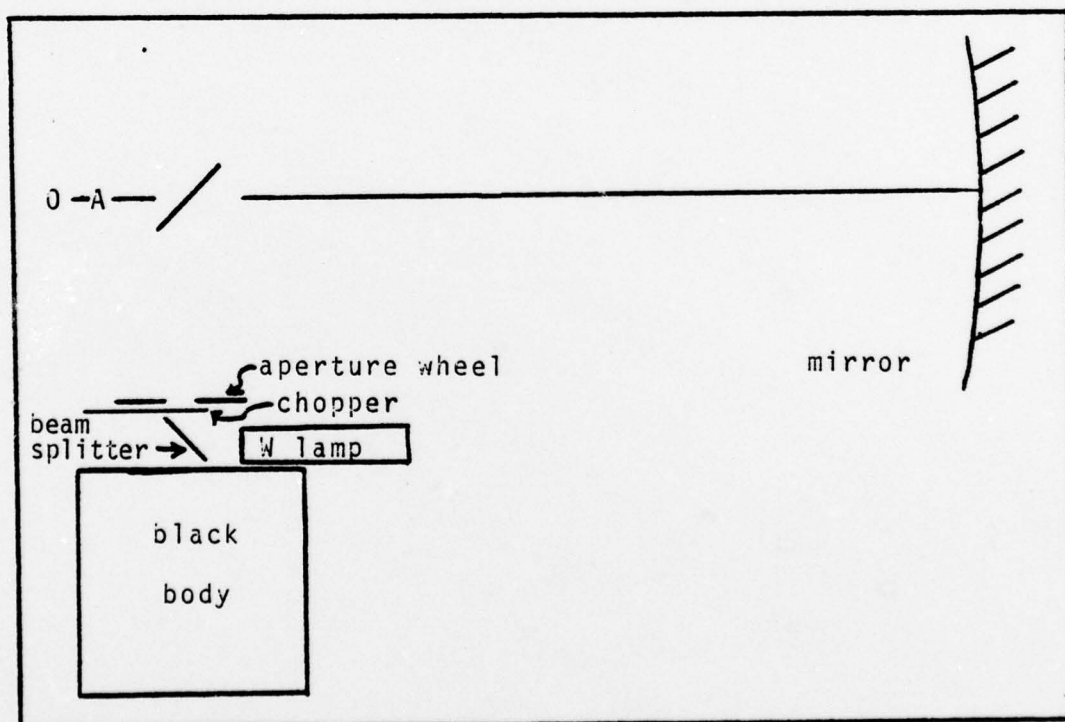
Fig. 2. Transmitter Assembly Layout

Receiver Assembly. The receiver assembly consists of
a Cassegrainean telescope, a continuously variable filter (CVF)
wheel, a detector and signal processing electronics. Figure 3
is a layout drawing of those components in the receiver head.
Three different receiver assemblies are used to cover the
spectral region from 0.5 to 14 micrometers; a silicon detector
is used for the spectral region from 0.5 to 1.2 micrometers,
an indium antimonide detector for 1.5 to 5.65 micrometers and
a mercury cadmium telluride detector for 7.6 to 14.3 micro-
meters. The field of view of the receiver is 5 mrad for the
visible receiver and 2.5 mrad for the IR receivers. The
electrical signal from each receiver head is carried by cable
to a separate electronics unit. Each electronics unit con-
tains signal amplifiers, a narrow band filter assembly to
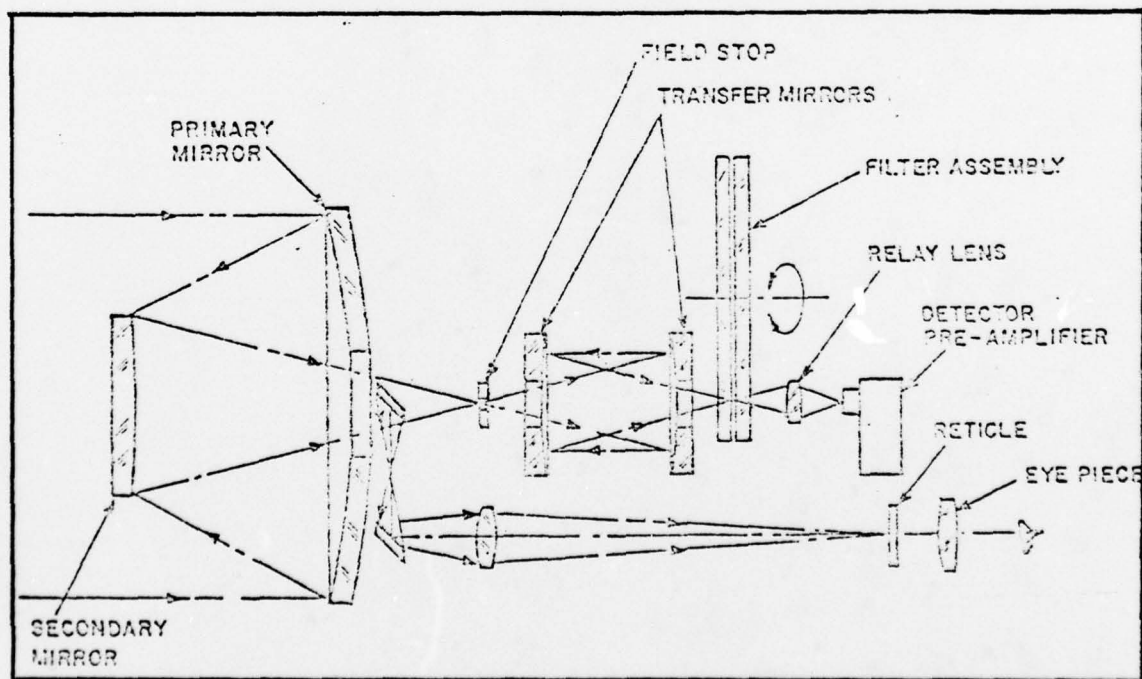
Fig. 3. Receiver Optical Layout

extract only the 1180Hz signal coming from the telescope, a
phase lock loop to synchronize the receiver electronics with
the telescope chopper, a digital meter and an analog meter
to display the transmission reading, the filter wheel drive
control and a binary coded digital output to provide trans-
mission and filter wheel position data for computer input.
During very low visibility conditions, synchronization may
be acheived by telephone modem or by radio transmission and
input of the synch signal generated by the telescope chopper.

Installation

The AFAL Targeting Systems Characterization Facility
consists of laboratory rooms on the eleventh and twelfth floors
of building 620 and a test area, the Trebein site, located
five miles east of building 620. The transmitter assembly
is installed in a building on the roof (fourteenth floor) of
building 620. The receiver assemblies are located in a sim-
ilar building at the Trebein site. The optical path is 7.944
kilometers long with an average elevation of 318 meters.
Meteorological instrumentation is installed at building 620,
at the Trebein site and on a tower located at the mid point
of the optical path. During the course of the experiment,
it was discovered that the weather tower interfered with the
optical line of sight between the transmitter and receiver
assemblies, and an additional objective of this thesis be-
came to determine the effect of the weather tower on the beam.

Calibration

The transmissometer manufacturer provided the calibra-

tion data which is found herein in appendix B. Because of
time constraints, it was necessary to accept this data and
to install the transmissometer for test. Using the manu-
facturer's data and equations (4), (5) and (6), it is possible
to determine the telescope's beam divergence, the distance to
crossover, the size of the central cone at the Trebein site
and the calibration factor. These are listed in Table I .

Table I

Transmissometer Beam Calculation Results

Source Aperture Diameter (inch)	Divergence (mrad)	Crossover Distance (km)	Central Cone Diameter (m)
0.0048(CAL)	0.097	4.32	0.35
.0081	.164	2.56	0.88
.0141	.285	1.47	1.85
.0256	.517	0.810	3.69
.0444	0.897	.467	6.71
.0810	1.636	.256	12.6
0.1410	2.848	0.147	22.2

Calibration factor: 3.73 (range= 7.944 km)

The manufacturer sent an engineer to Wright-Patterson
to accomplish the initial calibration prior to installation.
The calibration procedure detailed in appendix B was used
with the calibration factor of 3.78 (value for 8km) for the
peak response filter wheel position. All responses at other
filter wheel positions were then determined and filter fac-
tors were calculated to normalize all readings to the peak
response. The value of this technique is that no absolute

radiometric calibration is required. The limitations are the source output stability and optical transmission changes owing to dust deposits. As a result, periodic recalibration is required. Because of the difficulty of bringing the receiver assemblies to the transmitter assembly, an additional test is required to determine when recalibration is required. Developing this test is the principle objective of this thesis. It is discussed in the next chapter.

IV. The Experiment

As stated in chapter I, equipment malfunctions and
uncooperative weather prevented satisfying the objective of
conducting the initial transmission measurements as part of
the Targeting Systems Characterization Facility program.
Consequently, only the weather tower effects and the *in situ*
calibration verification procedure/test were accomplished for
this thesis. The work and the results are described in this
chapter. Note: The transmissometer manufacturer refers to
the InSB receiver as the near-Ir receiver; this erroneous
labelling is also used in this thesis in order to avoid con-
fusion.

Weather Tower Effects

Results. Initial alignment of the transmitter assem-
bly could not be accomplished until 4 August 1977. Alignment
was accomplished by removing the IR source and beam splitter
(see figure 1) and looking through a microscope at the image
in the plane of the source aperture. No alignment fixture
was available; as a result, on-axis alignment was determined
by lack of parallax and coma. The azimuth and elevation
settings were then adjusted until the appropriate window of
the Trebein building was in the center of the field of view;
the receivers were located behind the second window from the
north corner of the building; the transmitter was located
behind the farthest south window of the small building on the
top of the building 620 tower (see figure 5). Since electrical

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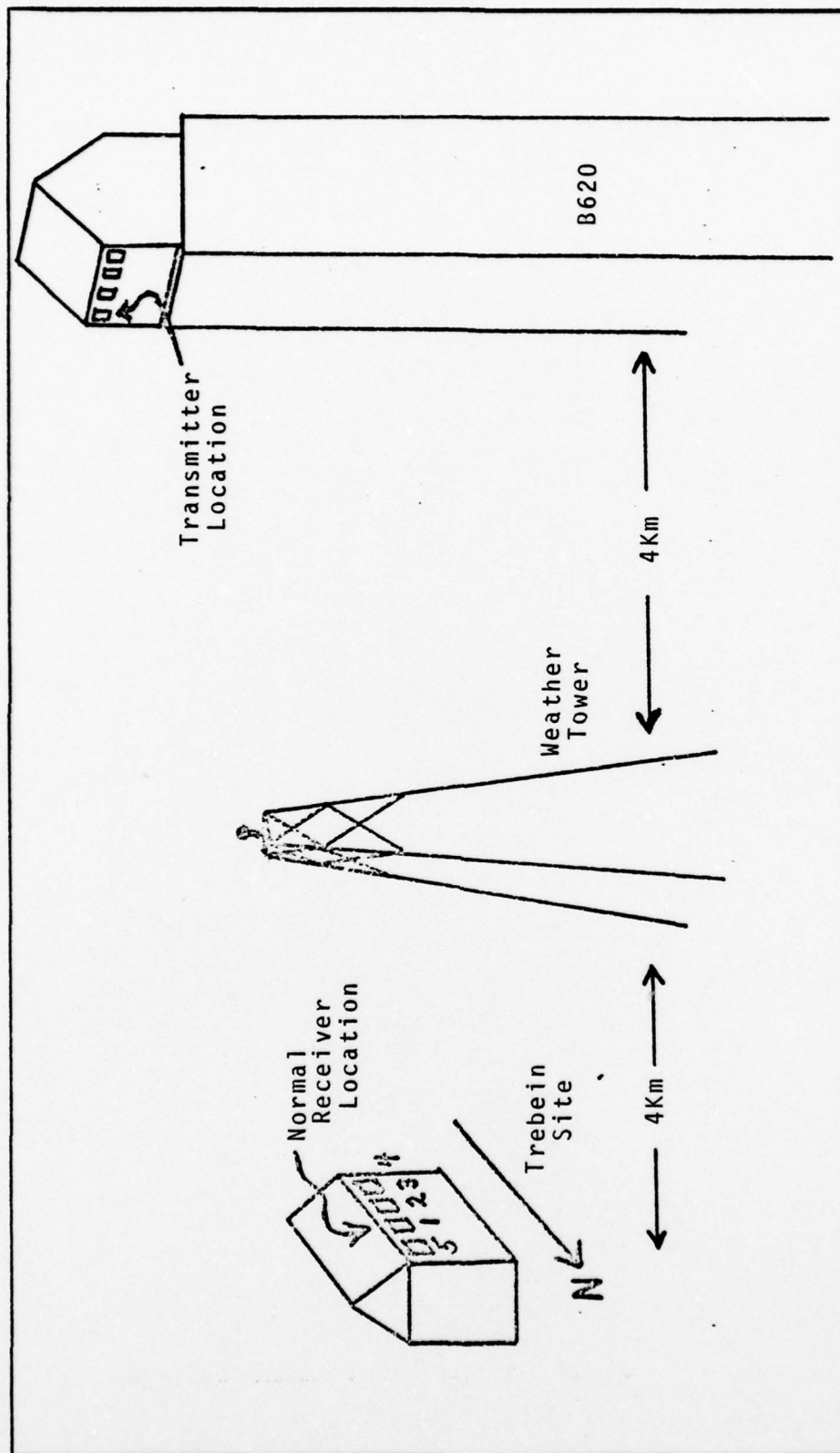
Fig. 4. Eight Kilometer Test Range.

power could not be applied to the transmitter assembly at
that time, no tests were conducted until 11 and 12 August.
Only the visible receiver could be used and it could not
maintain phase lock with the incoming beam. After several
days of troubleshooting, it became possible to conduct the
following test on 18 and 19 August 1977.

The transmitter assembly was visually aligned with the
appropriate window of the building at the Trebein site, and
the receiver was then aligned by manually adjusting its line-
of-sight until a maximum transmission reading was obtained.
Then, the size of the transmitter's source aperture was varied.
For each position of the aperture wheel, the transmission
reading was recorded; since the readings were fluctuating
rapidly, maximum and minimum values were estimated visually.
Only the 0.68μm position of the receiver filter wheel was used
during this test. Next, the receiver was placed on a tripod
in front of the next window (2) to the south, the transmitter
assembly was aligned to that window and the experiment was
repeated. A third set of measurements were also made for the
last window to the south. The same sets of measurements were
repeated the next day. The mean values of the data are
depicted on figure 6 where the numbers 1, 2, and 3 refer to
the receiver being located behind its normal window, the next
one to the south and the last one to the south, respectively.
The transmission readings were better on the first day because
the visibility was about 20 miles on the first day and only 15
miles on the second day. Image boil (scintillation) hampered
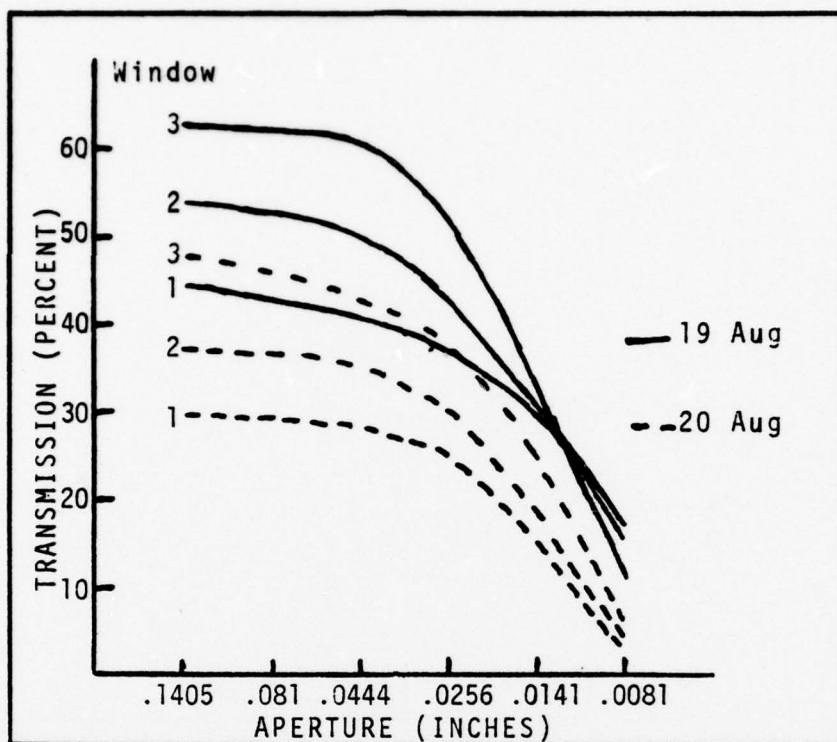
Fig. 5. Weather Tower Test Results, Day
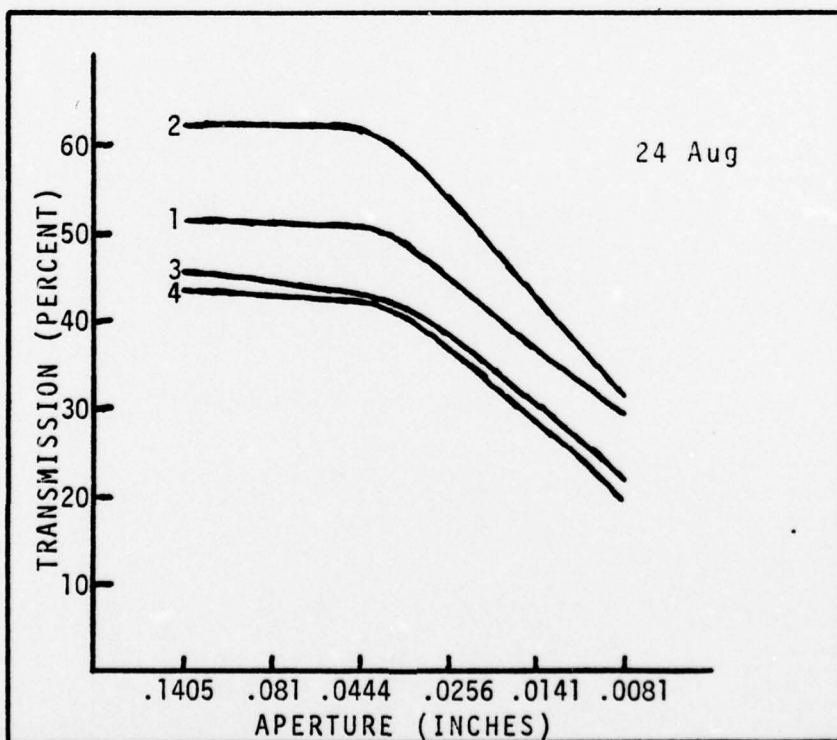
Fig. 6. Weather Tower Test Results, Night

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the visual alignment and was greater on the first day than on the second day.

The higher transmission readings as the receiver was moved farther south were quire disturbing because the weather tower obstructed the line-of-sight to the normal window (1) only! Consequently, it was decided to repeat the experiments at night when atmospheric optical turbulence would be less and a more precise alignment could be assured. The experiment was repeated the night of 24 August 1977; this time a fourth test position was included, the stairs outside the south side of the building. The data are depicted in figure 7 and listed in table II. A flashlight located at the receiver was used to assure precise alignment of the transmitter assembly. This time the lowest transmission readings are those for the farthest south window (3) and the stairs (4) while the highest readings are still for the southern window (2) adjacent to the normal window (1). As a final check, these measurements were repeated the night of 22 September 1977. Since the visible receiver was not functioning this time, the near IR receiver was used; the filter wheel was stationary at 2.19μm. These data are also included in table II; this time the northern window (5) adjacent to the normal window (1) was included. The measurements at the adjacent southern window (2) are still higher than for the other windows.

Additional information noted during these two tests:
1. As would be expected, based on the field of view plots in the manufacturer's calibration data, the transmission reading

Table II. Weather Tower Effect Transmission Measurements

Source Aperture Visible Transmission Reading 24 Aug 77

Diameter (inch)	Pos'n 1	Pos'n 2	Pos'n 3	Pos'n 4
0.1405	51.5±5.4**	61.9±4.5**	45.5±3.5	43.5±2.8
.0810	50.0±5.9	61.5±4.9	43.7±2.6	43.8±2.7
.0444	50.7±4.1	61.7±4.6	42.9±2.5	42.7±1.9
.0256	45.5±4.8	54.0±5.0	38.5±2.8	36.4±3.4
.0141	33.8±6.8	39.2±2.0	29.3±2.5	28.2±1.7
0.0081	29.2±2.2	31.7±2.0	22.1±1.8	17.0±3.0

Near IR Transmission Reading 22 Sep 77

Diameter (inch)	Pos'n 1	Pos'n 2	Pos'n 3	Pos'n 4	
0.1405	19.8±2.4	37.2±4.8**		19.1±3.3	P
.0810	19.3±1.8	36.2±4.1		19.5±2.5	O
.0444	19.1±1.8	35.3±3.1		18.7±2.3	S
.0256	14.6±2.0	31.4±4.0		14.9±2.3	N
0.0141	9.0±1.4	23.0±2.6		8.7±2.0	5

** Scintillation was high during these measurements.

is extremely sensitive to receiver misalignment. According
to that data, over 35 per cent is lost in transmission reading
by angular displacements as small as ±1 mrad. Consequently,
any flexing in the floor support of the receiver would cause
the transmission reading to change when the person accomplish-
ing the receiver alignment moved away from the receiver. This
applies to positions 3 and 4.

2. The peak sensitivity position is not necessaryily in the
center of the circle superimposed in the optical viewfinder
image.

3. Changing the near IR electronics drawer position can change
the transmission reading by as much as 10 to 15 per cent.

4. Turning the visible light source off reduced the near IR transmission reading from over 40 per cent down to 10 per cent.

5. If the receiver is at one window and the transmitter assembly is aligned with the adjacent window, the transmission readings are substantially lower than would be predicted for the larger source apertures and vary substantially less as a function of source aperture size. Representative data are shown in table III including an indication as to whether or not the central spot size should overlap the adjacent window.

6. Scintillation increases the spread in the data even for the largest aperture.

Table III. Adjacent Window Measurements

Source Aperture Diameter (inch)	Transmission Reading	Spot Size Overlap ?
0.1405	12.0	yes
.0810	12.2	yes
.0444	10.7	yes
.0256	9.1	marginal
.0141	8.6	no
0.0081	8.6	no

NOTE: The readings increased to 19.0 when the transmitter assembly was aligned to this window.

Discussion. The results of the weather tower tests do not demonstrate conclusively that the tower does or does not have an effect on transmission measurements made at windows one or five. However, the data do permit one general conclusion to be drawn; that the beam profile is not as predicted from theory (see Table I) but has a smaller central cone. The

justification for this conclusion is contained in the follow-
ing paragraphs.

Consider the slopes of the data plotted in figure 5.
Variable alignment would explain the crossover on the 19 August
data while different amounts of scintillation would account for
the difference in slopes with the lower scintillation yielding
the shallower slope on 20 August. The latter point is con-
firmed by the fact that the spread between the maximum and
minimum readings was also reduced for less scintillation.
Since using a flashlight at night helped eliminate the possi-
bility of misalignment, the remainder of this discussion will
be concerned only with the 24 August and 22 September data
(figure 6 and table II).

At night, scintillation was quite a bit less than
during the day and precise alignment of the transmitter
assembly was assured by using a flashlight located at the
receiver at the Trebein site. Although the slopes are even
flatter, they still exist; the first aperture showing marked
fall-off is the 0.256 aperture. Also, the difference between
maximum and minimum readings is as great during the maximum
scintillation period at night as during the day even though
the scintillation appeared to be less visually; i.e., although
the image of the flashlight sometimes moved out of the .0081
in. aperture at night, during the day the whole scene "crawled",
and the image of the window sometimes moved most of the way out
of the .0256 in. aperture. Since the diameter of the uniformly
irradiated central cone is 3.69m for the 0.256 in. aperture,

nighttime scintillation should not reduce the transmission
reading unless the central cone is smaller than predicted or
is not uniform. Since the diameter of the central cone is
only 0.88m for the 0.0081 in. aperture and 1.85m for the
0.0141 in. aperture, the transmission reading should be
reduced by scintillation and the spread from maximum to mini-
mum should be increased because the receiver would more often
be illuminated by the energy from outside the central cone.
The reading is reduced, but the spread is not increased; in
fact, the spread is reduced. This also is explicable if the
central cone is smaller than predicted. Finally, consider
table III. If the central cone were as large as predicted,
whenever the transmitter is aligned with one window, the
transmission reading should be the same at the adjacent window
as long as the central cone covers both windows. This is not
the case; and, in fact, the transmission reading is still
37 per cent lower even when the central cone should be 22m
(0.141 in. aperture).

The above comments are applicable to the data from
each window considered by itself. When the data from the
windows are compared to each other, it is obvious that at
night, window two consistently provided higher transmission
readings than the other positions. This can be traced to ease
of alighment; at the southernmost window (3) and on the stairs
(4), the flexibility of the floor is such that when the indi-
vidual aligning the receiver moves away from it, its boresight
is shifted. Also, at the normal window (1), the receiver

mounts were such that it was very difficult to "tweak" the boresight to within $\pm$ 0.5 mrad to assure maximum transmission readings.

Calibration Test

Results. The modified LOWTRAN program was run to plot transmission as a function of wavelength and dew point and visibility. Samples of the three spectral region runs using the rural aerosol model are shown in figures 7 through 11. These plots were used in conjunction with the manufacturer's spectral calibration data to select the wavelengths to be used for the calibration tests. The tests were not run until the night of 24 September because, at first, gaseous nitrogen was not available and then the weather was too hazy; recall, the tests must be accomplished when scattering is not the principle attenuation mechanism. Only the near IR was available the night of the test. The results of the measurements are included in table V along with the LOWTRAN predictions using the rural, urban, and maritime aerosol models. The meteorological conditions during the test are listed in table IV.

Table IV. Meteorological Conditions During Cal Test

Parameter	B620	Trebein	Model
Temperature (°C)	18	15	16
Dew Point (°C)	13	14	14
Visibility (stat. mi)	12 (base wx)	8.5	8.5, 10, 12
Pressure (millibars)		985	985

Table V. Spectral Transmission Data

NOMINAL WAVELENGTH (μm)	MEASURED TRANSMISSION	LOWTRAN VISIBILITY (KM)								
		RURAL MODEL			URBAN MODEL			MARITIME MODEL		
		13.7	19.3	16.1	13.7	19.3	16.1	13.7	19.3	16.1
1.69	71.5 ± 5.4	54.8	62.9	58.9	46.2	55.1		17.0	27.4	
1.73	64.0 ± 6.2	44.0	50.2	47.0	36.9	44.3	40.6	13.6	21.8	17.3
2.23	67.7 ± 6.2	66.8	73.1	70.0	56.4	64.8	60.5	21.5	32.7	26.7
2.27	66.2 ± 6.0	68.1	74.3	71.2	57.6	66.0	61.8	22.2	33.5	27.4
3.99	64.4 ± 6.2	54.8	58.5	56.7	50.1	54.9	52.5	21.4	30.0	25.5
4.03	60.7 ± 3.7	50.8	51.2	52.5	46.5	50.9	48.7	20.0	28.0	23.8
4.05	56.0 ± 5.2	47.4	50.5	49.0	43.4	47.5	45.5	18.8	26.2	22.3
4.62	19.5 ± 2.8	26.0	27.7	26.9	24.2	26.3	25.2	11.6	15.6	13.5
4.67	26.2 ± 2.8	30.5	32.4	31.4	28.3	30.8	29.6	13.7	18.4	15.9
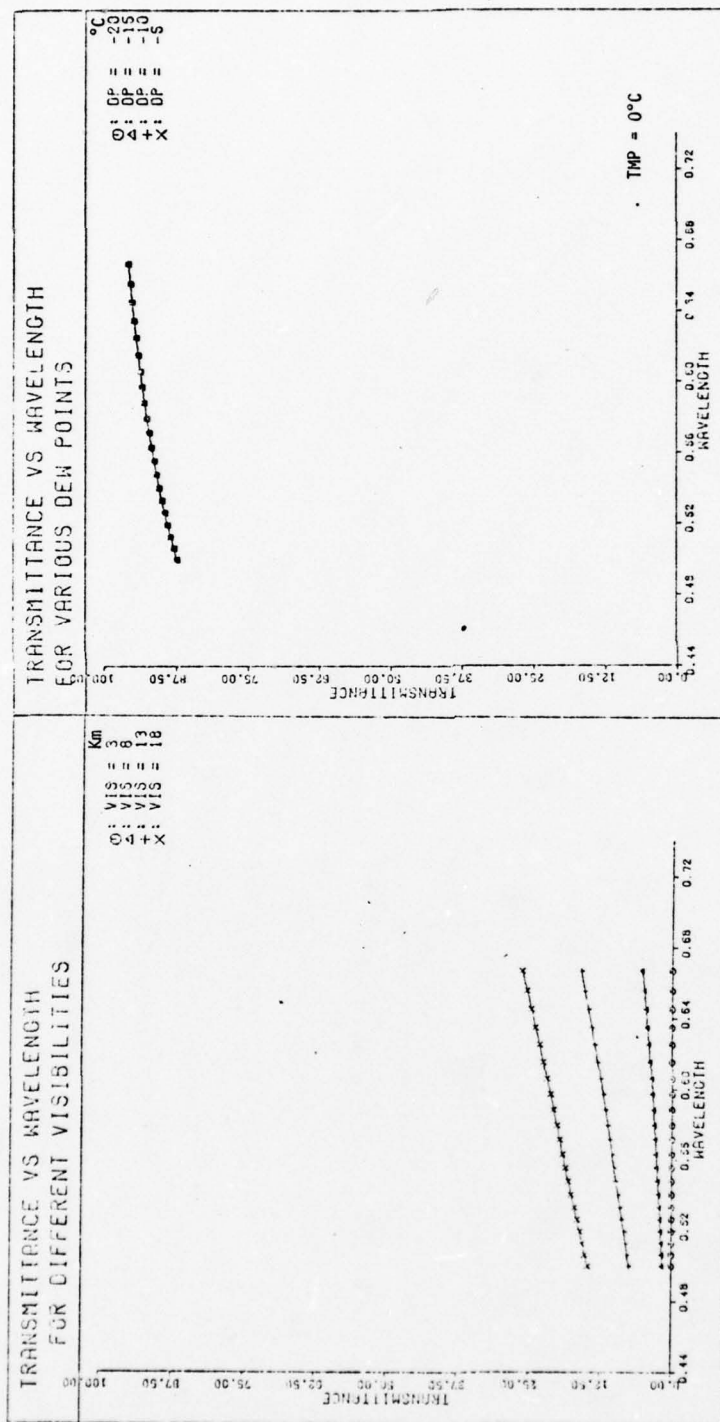
Fig. 7. Visible Spectral Transmission for Several Visibilities and Water Vapor Contents

Fig. 7. Continued

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Fig. 8. Near IR Spectral Transmission for Several Visibilities and Water Vapor Contents

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Fig. 8. Continued

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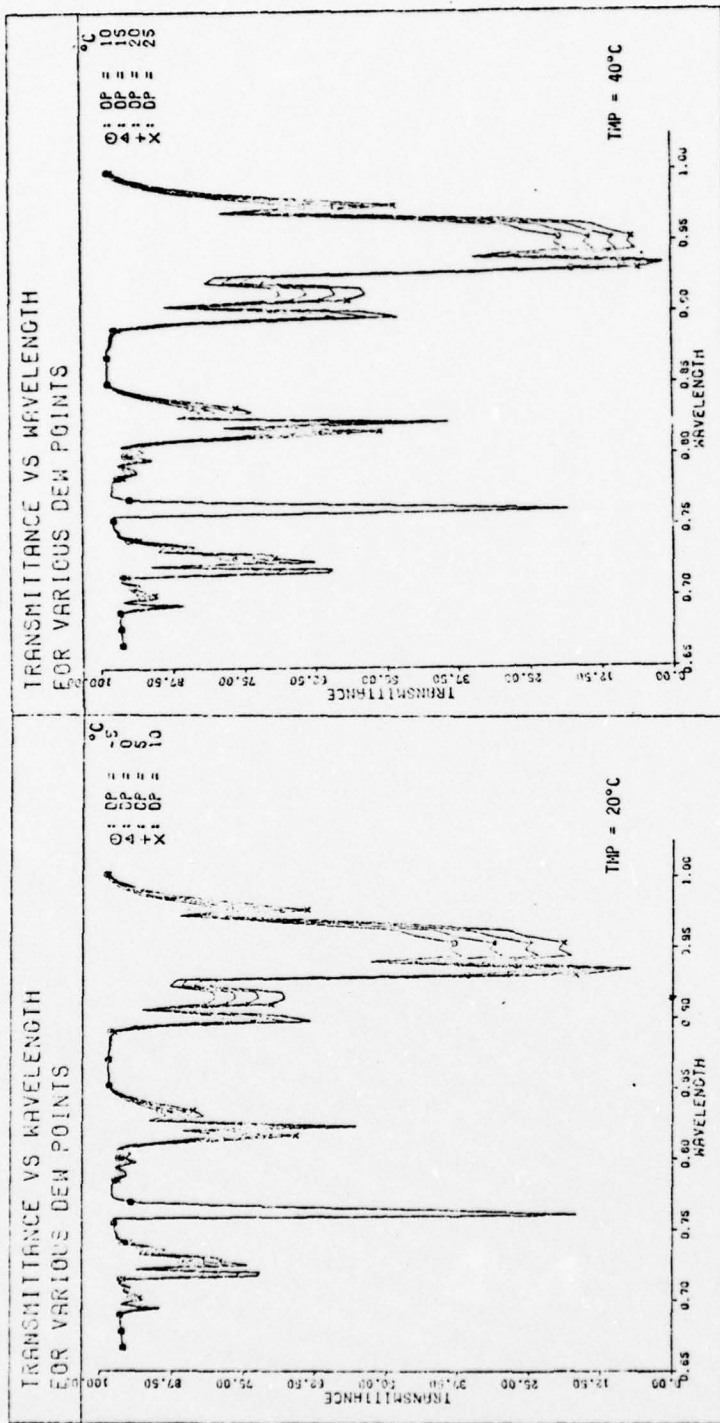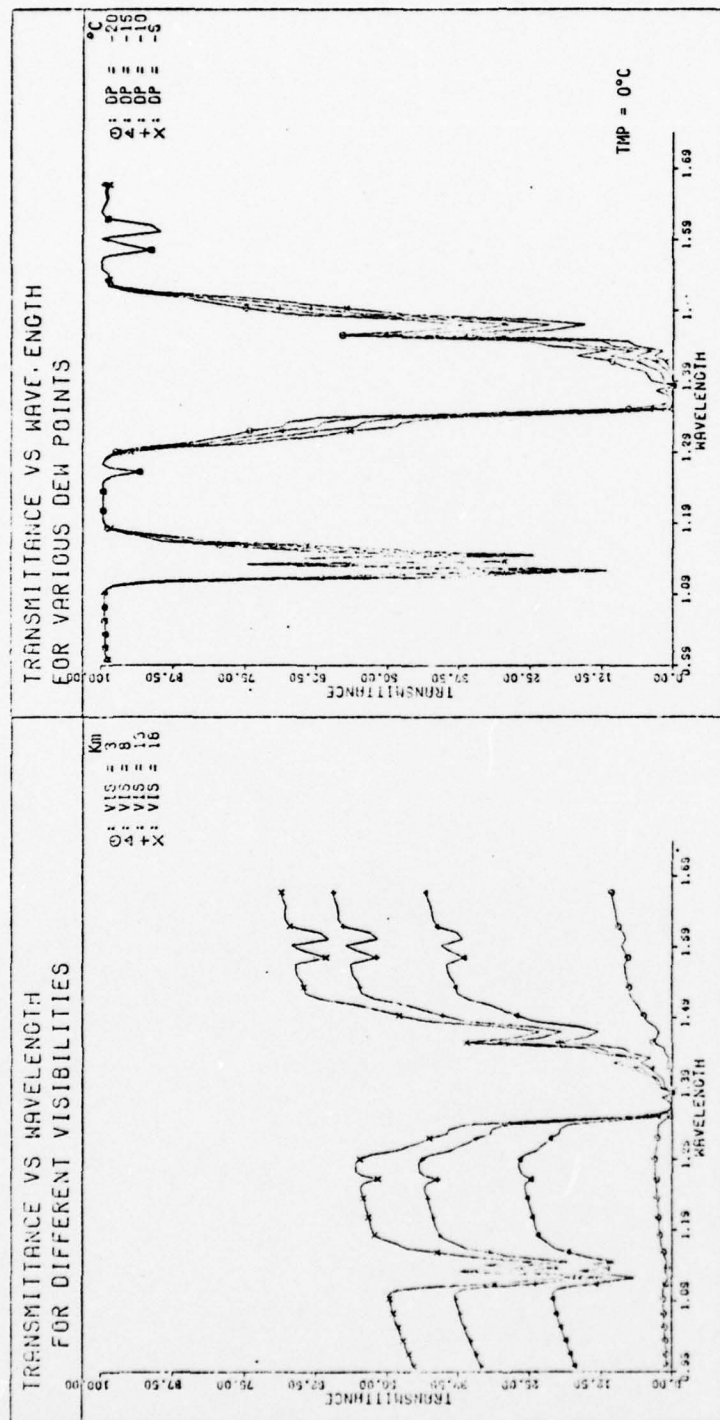
Fig. 9. Middle IR Spectral Transmission for Several Visibilities and Water Vapor Contents

Fig 9. Continued

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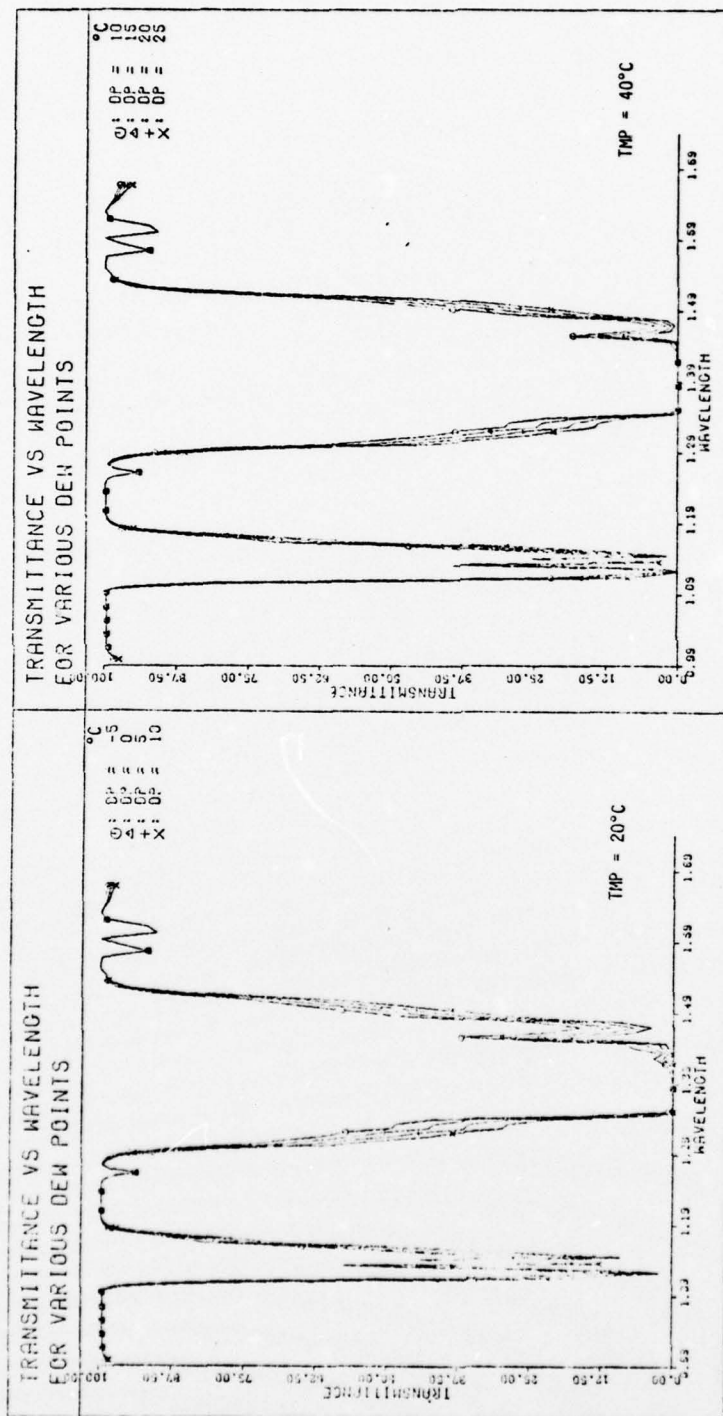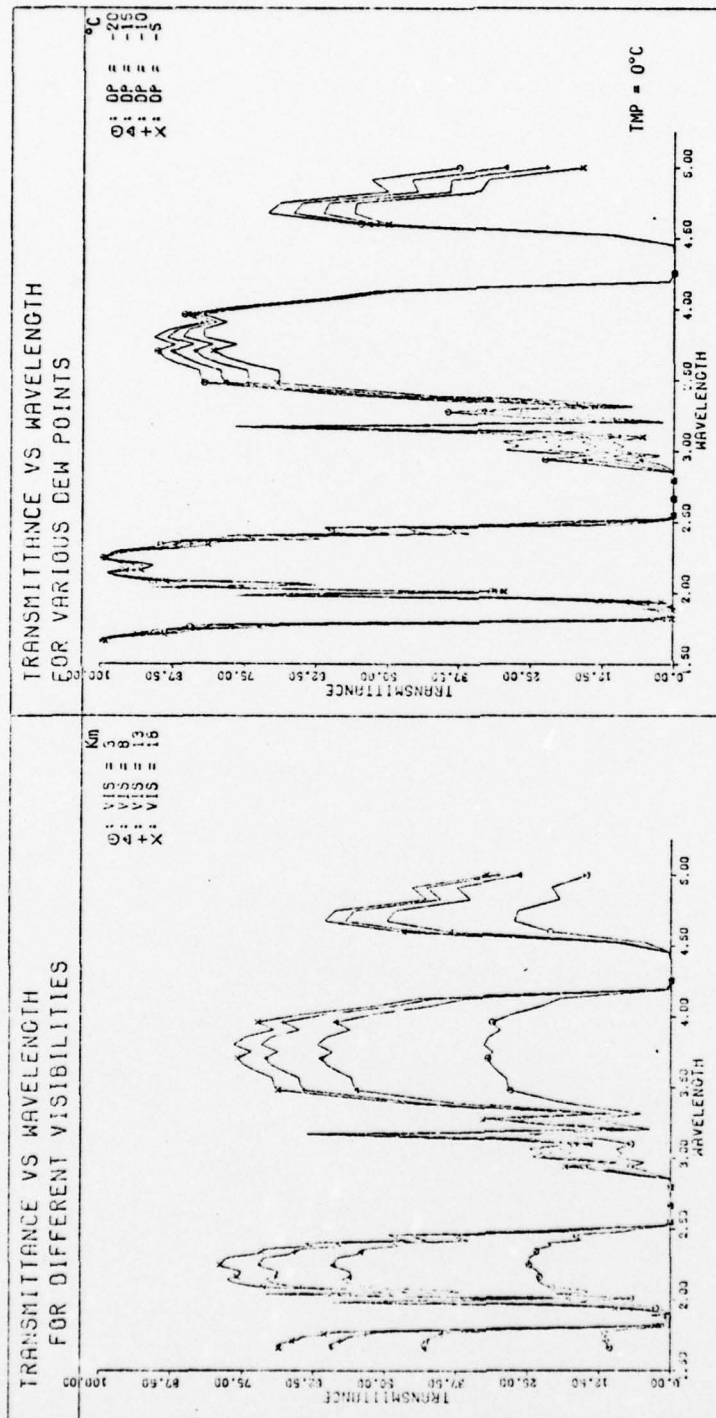
Fig. 10. Middle IR Spectral Transmission for Several Visibilities and Water Vapor Contents

Fig. 10. Continued

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Fig. 11. Far IR Spectral Transmission for Several Visibilities and Water Vapor Contents
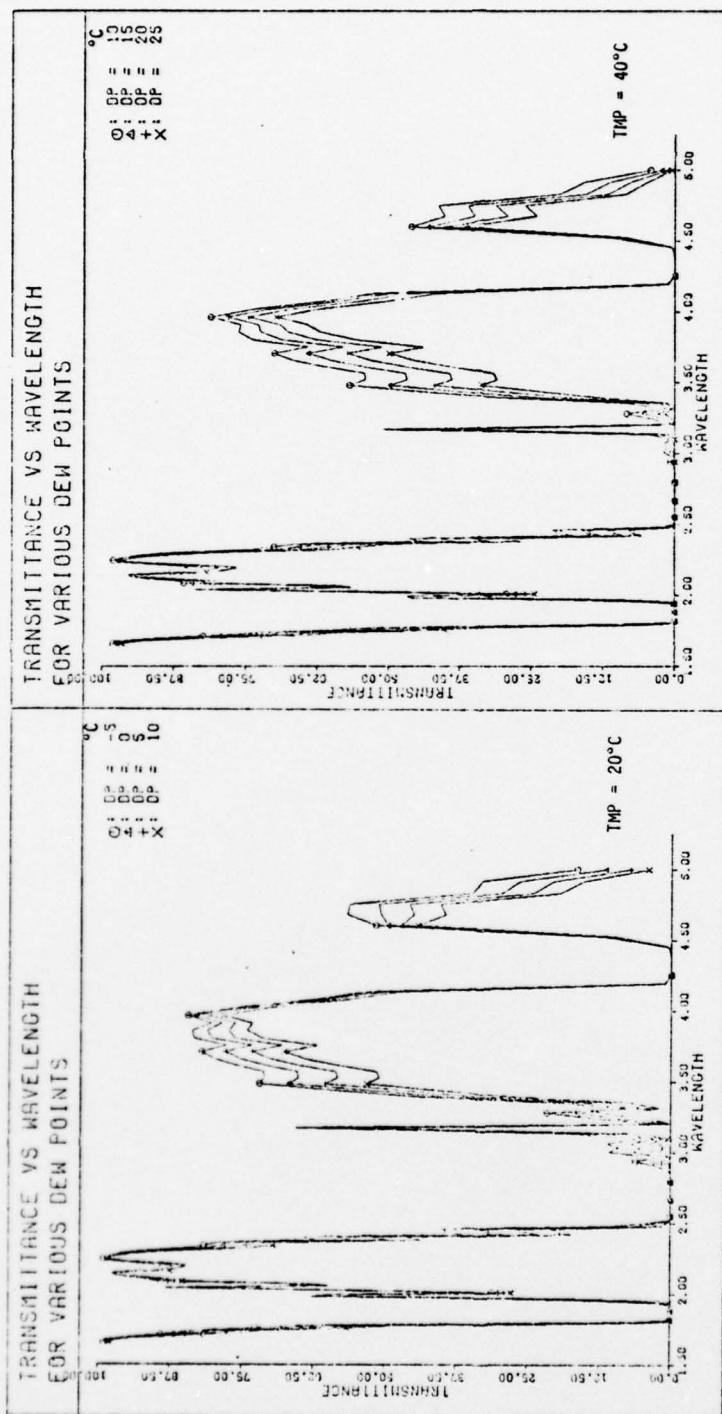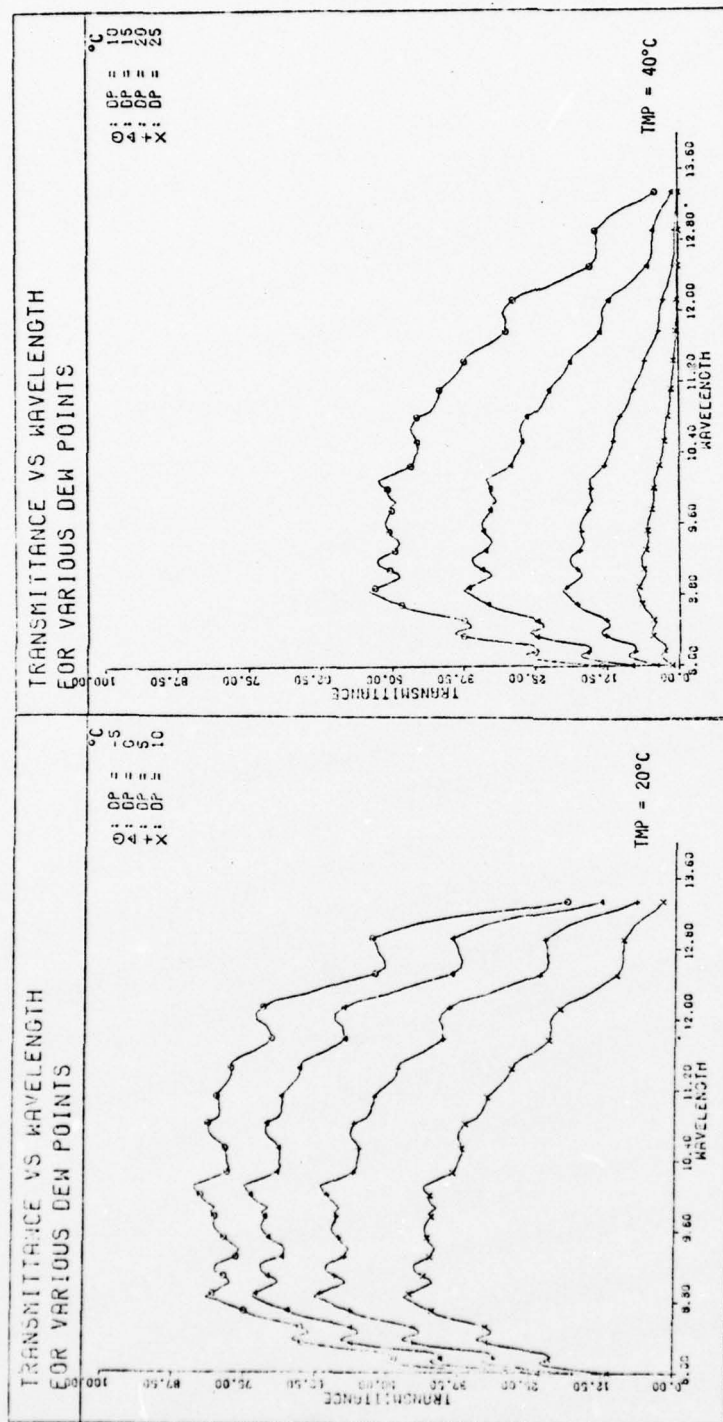
Fig. 11. Continued

After the *in situ* tests were completed, the near IR receiver and the electronics unit were brought to building 620. The dust cover was removed from the transmitter assembly, and the receiver was installed on an adjustable mount looking directly into the transmitter assembly. The calibration procedure of Appendix B was followed. Precision control of azimuth and elevation pointing angles was not possible; consequently, a great deal of time was required for each alignment, and the final alignment was still questionable. The temperature of the IR blackbody is not monitored by the control electronics; it did not look as deep red as during the *in situ* tests. The highest transmission reading for the CAL aperture, with the 10X attenuator in place, was 7.8 per cent. Moving the electronics drawer never caused the reading to exceed 20 per cent.

Discussion. With one exception (1.73μm) the measured transmission values in table V are within 0.1 of the predicted values using the base weather visibility and the rural aerosol model in LOWTRAN III B; the lower 1σ limit for that one wavelength interval is also within 0.1. Consequently, the calibration check in building 620 should have confirmed that no recalibration was required; this was not the case. Unfortunately, the adjustable mount was too difficult to use and an accurate alignment could not be proven. In addition, the variable transmission reading as a function of electronics drawer position caused much uncertainty in the procedure. Insufficient time remained to procure another mount and to

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repeat the experiment to demonstrate the efficacy of the *in situ* calibration check. The drawer position problem was subsequently traced to a faulty ground.

V. Observations and Recommendations

Observations

Using the Transmissometer. Because the transmitter beam central cone is not as large as expected, both the transmitter assembly and the receivers should be aligned prior to each test. Unfortunately, this will restrict test operations to days in which the visibility is five miles or greater. If the present transmitter mount proves to be sufficiently stable so that the realignment is not required, test days will still be restricted to those on which the transmission is greater than three per cent. This is because over half of the visible and almost half of the near IR channels have such low filter factors that the indicated transmission will be less than one per cent and the receiver will lose synch.

Also, scintillation appears to have a strong effect on the measurements. The frequency and amplitude of its effects are such that single point, instantaneous sampling could lead to an incorrect value.

Calibration. Although the current through the visible source is monitored and is constant, the radiation output will still change as the source ages. This leads to the need to recalibrate all three receivers, not just the visible receiver.

The temperature, dew point and visibility values at building 620, the Trebein site and Patterson field differ enough that more samples should be used, and the LOWTRAN calculation should be accomplished by steps between the sampling points.

Recommendations

1.   Use receiver mounts with precision azimuth and elevation controls similar to those for small astronomical telescopes.

2.   Use a rotary table with the same kind of mounts for calibration.

3.   Permanently mount and boresight a high power telescope on top of the transmitter assembly. This will permit alignment without removing the IR source and beam splitter.

4.   After three is accomplished, conduct a beam uniformity test and repeat the tower test.

5.   Monitor the IR source temperature.

6.   Provide an external synch for the receiver electronics.

7.   Monitor temperature, dew point and visibility at all three meteorological instrumentation positions and, when using LOWTRAN, calculate the path transmission incrementally.

8.   Determine the temperature/dew point variance along the path to determine if additional weather towers are required.

9.   Verify the manufacturer's filter wheel spectral calibration and spectral resolution.

10.   Conduct *in situ* calibration tests every time the visibility is greater than 15 km; use the data to select the most appropriate aerosol model; rural, urban or none; to use for the calibration graphs in Appendix B.

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Appendix A

Source Listing: Modified LOWTRAN IIIB

```
      PROGRAM LT3HM (INPUT,OUTPUT,TAPE72,TAPE82,TAPE6=OUTPUT)
      DIMENSION HZ1(34),HZ2(6),EH(10)
      DIMENSION TR(67),FW(67),FO(67),HZ(2),TX(10),W(10)
      DIMENSION C1(2580), C2(1575), C3(1575), C4(133), C5(15), C8(102)
      DIMENSION VX(45),C7(45),C7A(45)
      F(A)=EXP(18.9766-14.9595*A-2.43882*A*A)*A
      DATA H7(1)/5H23 KM/,H7(2)/5H 5 KM/
      TXY=0
      READ (82,401) (HZ1(I),I=1,34)
      READ (82,401) (HZ2(I),I=1,5)
      H72(6) = HZ1(6)
      READ(82,431) (VX(I),C7(I),C7A(I),I=1,44)
      READ (82,403) (TR(I),FW(I),FO(I),I=1,57)
      READ (82,404) (C1(I),I=1,2580)
      READ (82,404) (C2(I),I=1,1575)
      READ (82,404) (C3(I),I=1,540)
      READ (82,405) (C4(I),I=1,133)
      READ (82,404) (C5(I),I=1,15)
      READ (82,405) (C8(I),I=1,102)
      JCNTR=0
      REWIND 72
    2 CONTINUE
      RCTR=0.0
      PRINT*,"ENTER,IHAZE;JP,JSPEC,JTTY (+I3)"
      READ*,IHAZE,JP,JSPEC,JTTY
      PRINT 400,IHAZE,JP,JSPEC,JTTY
      IF(JP.LE.2.AND.JSPEC.EQ.1)GO TO 903
      IF(JP.GT.2.AND.JSPEC.EQ.2)GO TO 903
      IF(JTTY.EQ.1.AND.IHAZE.EQ.7)IHAZE=1
      IF(IHAZE.NE.7) GO TO 250
      READ 431,(VX(I),C7(I),C7A(I),I=1,44)
      PRINT 431,(VX(I),C7(I),C7A(I),I=1,44)
      IHAZE = 1
  250 CONTINUE
      IF(JSPEC.NF.2)GO TO 107
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          IF(IXY.NE.3)GO TO 107                                      000450
          RANGE=RANGE+1.0                                            000460
          RCTR=RCTR+1.0                                              000470
          GO TO 105                                                  000480
107       CONTINUE                                                   000490
          IF(IXY.GT.3) GO TO 541                                     000500
          IF(JITY.EQ.0)GO TO 251                                     000510
          PRINT*,"ENTER H1,P,TMP,DP,RH,WH,VIS,RANGE(KM,MB,C,C,%,GM M-3,KM,KM000520
         1)"                                                         000530
251       READ*,H1,P,TMP,DP,RH,WH,VIS,RANGE                         000540
          PRINT 430,H1,P,TMP,DP,RH,WH,VIS,RANGE                     000550
          Z=H1                                                       000560
          J=IFIX(Z+1.0E-6)+1.                                        000570
          IF(Z.GF.25.0)  J=(Z-25.0)/5.0+26.                         000580
          IF(Z.GF.50.0)  J=(Z-50.0)/20.0+31.                        000590
          IF(Z.GF.70.0)  J=(Z-70.0)/30.0+32.                        000600
          IF(J.GT.33)J=33                                            000610
          FAC=Z-FLOAT(J-1)                                           000620
          IF(J.LT.26) GO TO 500                                      000630
          FAC=(Z-5.0*FLOAT(J-26)-25.)/5.                             000640
          IF(J.GF.31) FAC=(Z-50.0)/20.0                             000650
          IF(J.GF.32) FAC=(Z-70.0)/30.0                             000660
          IF(FAC.GT.1.0) FAC=1.0                                     000670
500       L=J+1                                                      000680
          IF(Z.GF.5.0)GO TO 520                                      000690
          AHZ2=HZ2(J)+(HZ2(L)/HZ2(J))**FAC                          000700
520       AHAZE=HZ1(J)+(HZ1(L)/HZ1(J))**FAC                         000710
541       CONTINUE                                                   000720
          IF(IXY.GT.2)GO TO 542                                      000730
          IF(JITY.EQ.0)GO TO 510                                     000740
          PRINT*,"ENTER,V1,V2,DV  (CM-1)"                           000750
510       READ*,V1,V2,DV                                            000760
          PRINT 406,V1,V2,DV                                        000770
542       PRINT 407,H1,RANGE                                        000780
          IF(VIS.GT.0.0) PRINT 417,VIS                              000790
```

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```
      IF(VIS.LT.2.0.AND.VIS.GT.0.0) PRINT 442                          000800
      IF (IHAZE.EQ.0.) PRINT 426                                        000810
      IF(VIS.LE.0.0.AND.IHAZE.GT.0) PRINT 416,IHAZE,H7(IHAZE)          000820
      AVW=10000./V1                                                     000830
      ALAM=10000./V2                                                    000840
      PRINT 418, V1,V2,DV,ALAM,AVW                                      000850
      AVW=6.5E-4*(V1+V2)                                               000860
      AVW=AVW*AVW                                                       000870
      CO=77.46+.459*AVW                                                 000880
      CW=43.487-0.3473*AVW                                            000890
   48 CONTINUE                                                          000900
      LAX1=1                                                            000910
      LAX2=1                                                            000920
      LAX3=1                                                            000930
      TMP=TMP-20.0                                                     000940
      DP=DP-5.0                                                        000950
      IF(JP.LE.2)GO TO 14                                              000960
      IF(JP.GT.3)GO TO 13                                              000970
      VIS=VIS-5.0                                                      000980
      LAX1=1                                                            000990
      LAX2=1                                                            001000
      LAX3=7                                                            001010
      IF(JSPFC.EQ.1)LAX3=4                                             001020
      GO TO 14                                                          001030
   13 LAX1=3                                                            001040
      LAX2=7                                                            001050
      IF(JSPFC.EQ.1)LAX2=4                                             001060
      LAX3=1                                                            001070
   14 CONTINUE                                                          001080
      SUMR=0.0                                                          001090
      SUMV=0.0                                                          001100
      SUMW=0.0                                                          001110
      DO 969 II=1,LAX1                                                 001120
      TMP=TMP+20.0                                                     001130
      IF(II.EQ.1)GO TO 15                                             001140
```

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```
      DP=DP-25.0                                                    001150
      IF(JSPFC.EQ.1)DP=DP+23.0                                      001160
 15   CONTINUE                                                      001170
      DO 909 JJ=1,LAX2                                              001180
      DP=DP+5.0                                                     001190
      DO 909 KK=1,LAX3                                              001200
      IF(JP.FQ.3)VIS=VIS+5.0                                        001210
      IF(IXY.EQ.1)GO TO 49                                          001220
      T=TMP+273.15                                                  001230
      TT=273.15/T                                                   001240
      IF(RH.LE.0.0)TT=273.15/(273.15+DP)                           001250
      IF(WH.LE.0.0)WH=F(TT)                                         001260
      IF(JP.FQ.4)WH=F(TT)                                           001270
      IF(RH.GT.0.0)WH=0.01*RH*WH                                   001280
      PS=P/1013.0                                                   001290
      TS=273.15/T                                                   001300
      X=PS*TS                                                       001310
      PT=PS*SQRT(TS)                                                001320
      D=0.1*WH                                                      001330
      EH(1)=D*PT**0.9                                               001340
      EH(2)=X*PT**0.75                                              001350
      FH(4)=0.8*PT*X                                                001360
      PPW=4.56E-5*D*273.15/TS                                       001370
      TS1 = (296.0/273.15)*TS                                       001380
      EH(5)= D*PPW*EXP(6.08*(TS1-1.0))+0.002*D*(PS-PPW)             001390
      FH(10)=D*(PPW+0.12*(PS-PPW))*EXP(4.56*(TS1-1.0))             001400
      FH(6)=X                                                       001410
      HAZE=AHAZE                                                    001420
      IF(Z.GE.5.0) GO TO 150                                        001430
      IF(IHAZE.EQ.2)HAZE=AHZ2                                       001440
      IF(VIS.LE.0.0) GO TO 150                                      001450
      HAZE=6.389*((AHZ2-AHAZE)/VIS+AHAZE/5.0  -AHZ2/23.0)          001460
 150  IF(HAZF.LT.0.0) HAZE=0.0                                      001470
      FH(7) = HAZE/AHAZE                                            001480
      WO=5.6E-05                                                    001490
```

```fortran
      EH(8)=46.6667*WO
      FH(3)=FH(8)*PT**0.4
      EH(9)=1.0
      REF= 1.0E-6*(CO*X*1013.0/273.15-PPM*GW)
105   DO 27 K=1,10
27    W(K)=RANGE*EH(K)
49    CONTINUE
      I=1
      L=1
      JCNTR=JCNTR+1
      IV1=V1/5.0
      IV2=V2/5.+.99
      IV1=5*IV1
      IV2=5*IV2
      IF (IV1.LT.350) IV1=350
      IF (IV2.GT.50J00) IV2=50000
      IF(DV.LT.5.)DV=5.
      IDV=DV
      N=FLOAT(IV2-IV1)/DV+1
      IF(II.EQ.1.AND.JJ.EQ.1.AND.KK.EQ.1)WRITE(72)JSPEC,JP,N
      IF(JSPEC.EQ.1.OR.(JJ.EQ.1.AND.KK.EQ.1))WRITE(72)TMP,DP,VIS
      IV=IV1-IDV
      ICOUNT=0
      SUMA=0.0
C****   BEGINNING OF TRANSMITTANCE CALCULATIONS
50    IV=IV+IDV
      IF(JP.EQ.0)GO TO 51
      IF(JP.EQ.2.OR.JSPEC.EQ.1)GO TO 51
      GO TO 52
51    IF(ICOUNT.EQ.50)ICOUNT=0
      IF(ICOUNT.EQ.0)PRINT 422
52    DO 53 K=1,10
      TX(K)=C.C
      IF (K.LT.4) TX(K)=1.0
53    CONTINUE
```

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53

```
      ICOUNT=ICOUNT+1                                          001850
      SUM=0.0                                                  001860
      V=IV                                                     001870
      I=(IV-350)/5+1                                           001880
      IF(IV.LT.670) GO TO 72                                   001890
      IF(IV.LE.3000) GO TO 61                                  001900
C*+++++*    MOLECULAR SCATTERING                               001910
      C6=9.807E-20*(V**4.0117)                                 001920
      TX(6)=C6*W(6)                                            001930
      SUM=SUM+TX(6)                                            001940
      IF (IV.LT.9200) GO TO 72                                 001950
      IF (IV.LT.13000) GO TO 69                                001960
C*+++++*   UV OZONE                                            001970
      IF (IV.LE.23400) GO TO 54                                001980
      IF (IV.GE.27500) GO TO 55                                001990
      GO TO 87                                                 002000
54    XX=200.0                                                 002010
      XI=(V-13000.0)/XX+1.0                                    002020
      L1=1                                                     002030
      L2=53                                                    002040
      GO TO 56                                                 002050
55    XX=500.0                                                 002060
      XI=(V-27500.0)/XX+57.0                                   002070
      L1=57                                                    002080
      L2=102                                                   002090
56    DO 57 NN=L1,L2                                           002100
      XD=XI-FLOAT(NN)                                          002110
      IF (XD) 59,58,57                                         002120
57    CONTINUE                                                 002130
58    TX(8)=W(8)*C8(NN)                                        002140
      GO TO 60                                                 002150
59    TX(8)=C8(NN)+XD*(C8(NN)-C8(NN-1))                        002160
      TX(8)=W(8)*TX(8)                                         002170
60    SUM=SUM+TX(8)                                            002180
      IF (IV.GT.14500) GO TO 87                                002190
```

```
      GO TO 69                                                     002200
C****** WATER VAPOR CONTINUUM   10 MICRON  REGION                  002210
51    IF(IV.GT.1350) GO TO 62                                      002220
      TX(5) = (4.18 + 5578.0 * EXP( -7.87E-3*V)) * W(5)            002230
      GO TO 66                                                     002240
62    IF(IV.LT.2350) GO TO 68                                      002250
C****** WATER VAPOR CONTINUUM  4 MICRON REGION                     002260
      XI = (V-2350.0) / 50.0 + 1.0                                 002270
      NH = XI + 1.001                                              002280
      XH = XI - FLOAT(NH)                                          002290
      TX(5) = C5(NH)                                               002300
      TX(5)=TX(5)+XH*(C5(NH)-C5(NH-1))                             002310
      TX(5)=TX(5)*W(10)                                            002320
66    SUM = SUM + TX(5)                                            002330
      IF(IV.LE.1350.OR.IV.GT.2740) GO TO 72                        002340
C****** NITROGEN CONTINUUM                                         002350
58    IF (IV.LT.2080) GO TO 72                                     002360
      K4=I-346                                                     002370
      TX(4)=C4(K4)*W(4)                                            002380
      SUM=SUM+TX(4)                                                002390
      GO TO 72                                                     002400
C****** WATER VAPOUR                                               002410
59    IF (IV.LT.12810.AND.IV.GE.9875) GO TO 70                     002420
      IF (IV.LE.14520.AND.IV.GE.13400) GO TO 71                    002430
      GO TO 76                                                     002440
70    I=I-135                                                      002450
      GO TO 72                                                     002460
71    I=I-255                                                      002470
72    K1=1                                                         002480
      IF (W(1).LT.1.0E-20) GO TO 76                                002490
      WS1=ALOG10(W(1))+C1(I)                                       002500
      IF (WS1.LT.-2.3466) GO TO 76                                 002510
      IF (WS1.GT.3.5682) GO TO 75                                  002520
      IF (WS1.GT.2.0) K1=40                                        002530
      DO 73 K=K1,67                                                002540
```

55

```
         IF (WS1.LE.FW(K)) GO TO 74
73       CONTINUE
74       TX(1)=TR(K)+(TR(K-1)-TR(K))*(FW(K)-WS1)/(FW(K)-FW(K-1))
         GO TO 76
75       TX(1)=0.0
76       CONTINUE
C****** **     UNIFORMLY MIXED GASES
         IF (IV.LT.8060.AND.IV.GE.500) GO TO 77
         IF (IV.LT.13190.AND.IV.GT.12970) GO TO 78
         GO TO 83
77       J=I-30
         GO TO 79
78       J=(IV-12950)/5+1516
79       IF(W(2).LT.1.0E-20) GOTO 83
         K1=1
         WS2=ALOG10(W(2))+C2(J)
         IF (WS2.LT.-2.3468) GO TO 83
         IF (WS2.GT.3.5682) GO TO 82
         IF (WS2.GT.2.0) K1=40
         DO 80 K=K1,67
         IF (WS2.LE.FW(K)) GO TO 81
80       CONTINUE
81       TX(2)=TR(K)+(TR(K-1)-TR(K))*(FW(K)-WS2)/(FW(K)-FW(K-1))
         GO TO 83
82       TX(2)=0.0
83       CONTINUE
C****** **     OZONE
C****CALCULATED FOR Z.LT.2 WITH WO.EQ.5.5E-05
         IF (IV.LT.575.OR.IV.GT.3270) GO TO 87
         L=I-45
         K1=1
         IF (W(3).LT.1.0E-20) GO TO 87
         WS3=ALOG10(W(3))+C3(L)
         IF (WS3.LT.-1.6778) GO TO 87
         IF (WS3.GT.3.9345) GO TO 86
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56

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           IF (WS3.GT.1.5) K1=36                                        00 2900
           DO 34 K=K1,67                                                0029 10
           IF (WS3.LE.FO(K)) GO TO 85                                   002920
     84    CONTINUE                                                     002930
     85    TX(3)=TR(K)-(TR(K)-TR(K-1))*(FO(K)-WS3)/(FO(K)-FO(K-1))     002940
           GO TO 87                                                     002950
     86    TX(3)=0.0                                                    002960
     87    CONTINUE                                                     002970
     C******* AEROSOL EXTINCTION                                        002980
           ALAM=1.0E+4/V                                                002990
           XX=0.0                                                       003000
           YY=0.0                                                       003010
     C******* TEMPORARY FOG CORRECTION FOR VIS BELOW 2 KM.              003020
           IF(IHA7E.EQ.0)GO TO 90                                       003030
           IF(VIS.GT.0.0.AND.VIS.LT.2.0)  XX = 3.91/VIS                 003040
           IF(XX.GT.0.0)GO TO 90                                        003050
           DO 88 NN=1,44                                                003060
           XD=ALAM-VX(NN)                                               003070
           IF(XD)89,88,88                                               003080
     88    CONTINUE                                                     003090
     89    XX=(C7(NN)-C7(NN-1))*XD/(VX(NN)-VX(NN-1))+C7(NN)            003100
           YY=(C7A(NN)-C7A(NN-1))*XD/(VX(NN)-VX(NN-1))+C7A(NN)         003110
     90    TX(10)=YY*W(7)                                               003120
           TX(7)=XX*W(7)                                                003130
           SUM=SUM+TX(7)                                                003140
           TX(9)=SUM                                                    003150
           DO 94 K=4,10                                                 003160
           IF (TX(K).EQ.0.0) GO TO 92                                   003170
           IF (TX(K).LE.0.1) GO TO 91                                   003180
           IF (TX(K).GT.20.) GO TO 93                                   003190
           TX(K)=EXP(-TX(K))                                            003200
           GO TO 94                                                     003210
     91    TX(K)=1.0-TX(K)+0.5*TX(K)*TX(K)                             003220
           GO TO 94                                                     003230
     92    TX(K)=1.0                                                    003240
```

57

```
       GO TO 94                                                        003250
33     TX(K)=0.                                                        003260
94     CONTINUE                                                        003270
       SUMV=SUMV+TX(7)                                                 003280
       HOH=TX(1)*TX(5)                                                 003290
       IF(JP.EQ.2.AND.JTTY.EQ.1)WRITE(6,443)HOH                        003300
       SUMW=SUMW+HOH                                                   003310
       TX(10)=1.0-TX(10)                                               003320
       TX(9)=TX(1)*TX(2)+TX(3)*TX(9)                                   003330
       IF (IV.GE.13000) TX(3)=TX(8)                                    003340
       AB=1.0-TX(9)                                                    003350
       IF(IV.EQ.IV1.OR.IV.EQ.IV2) AB=0.5*AB                           003360
       SUMA=SUMA+AB*DV                                                 003370
       IF(JP.EQ.0.OR.JP.EQ.2)WRITE(6,423)IV,ALAM,TX(9),(TX(K),K=1,7),  003380
      1TX(10),SUMA                                                     003390
       TF(JSPEC.EQ.1)WRITE(6,423)IV,ALAM,TX(9),(TX(K),K=1,7),TX(10),SUMA 003400
       TN=TX(9)*100                                                    003410
       IF(JP.EQ.2)WRITE(72)ALAM,TN                                     003420
       IF(JSPEC.EQ.1)WRITE(72)ALAM,TN                                  003430
       IF (IV.GE.IV2) GO TO 95                                         003440
       GO TO 50                                                        003450
95     AB = 1.0 - SUMA/ FLOAT(IV2-IV1)                                 003460
       PRINT 424,IV1,IV2,SUMA,AB                                       003470
       PRINT*," TMP=",TMP," DP=",DP," VIS=",VIS," JP=",JP," JSPEC=",JSPEC 003480
       PRINT*,"RANGE=", RANGE                                          003490
       IF(JP.LT.2)GO TO 909                                            003500
       PRINT*,"N=",N                                                   003510
       SUMW=SUMW/N                                                     003520
       SUMV=SUMV/N                                                     003530
       IF(SUMV.LE.0.0)PRINT*,"SUMR WON'T COMPUTE"                      003540
       SUMR=0.999                                                      003550
       IF(SUMV.GT.0.0)SUMR=AB/(SUMV*SUMW)                              003560
       PRINT 445,SUMW                                                  003570
       PRINT 446,SUMV                                                  003580
       PRINT 447,SUMR                                                  003590
```

58

```
      SUMV=100*SUMV
      SUMW=100*SUMW
      IF(JSPEC.EQ.1)GO TO 686
      IF(JP.EQ.3)WRITE(72)VIS,SUMV
      IF(JP.EQ.4)WRITE(72)DP,SUMW
686   CONTINUE
      SUMR=0.0
      SUMV=0.0
      SUMW=0.0
909   CONTINUE
      IF(JSPEC.NE.2)GO TO 106
      IF(RANGE.GE.25.0.OR.A3.LE.0.0001)GO TO 106
      IXY=3
      GO TO 250
106   IF(JTTY.EQ.1)PRINT*,"ENTER IXY (I3)"
      READ 400,IXY
      IF(JSPEC.EQ.2)RANGE=RANGE-RCTR
      RCTR=0.0
      PRINT*,"JCNTR= ",JCNTR
      PRINT*,"IXY= ",IXY
      IF(IXY.EQ.0) GO TO 100
      GO TO (96,2,107,97,100), IXY
96    IF(JTTY.EQ.0)GO TO 787
      PRINT*,"ENTER V1,V2,DV  (CM-1)"
787   CONTINUE
      READ*, V1,V2,DV
      AVW=10000./V1
      ALAM=10000./V2
      PRINT 418, V1,V2,DV,ALAM,AVW
      IF(JP.LE.2)GO TO 48
97    IF(JP.NE.3)GO TO 98
      VIS=VIS-30.0
      IF(JSPEC.EQ.1)VIS=VIS+15.0
      IF(IXY.EQ.1)GO TO 48
      IF(IXY.EQ.4)GO TO 2
```

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```
98    IF(JP.NE.4)GO TO 2                                                003950
      WH=0.0                                                            003960
      TMP=TMP-40.0                                                      003970
      DP=DP-50.0                                                        003980
      IF(JSPEC.EQ.1)DP=DP+5.0                                           003990
      IF(IXY.EQ.1)GO TO 48                                              004000
      IF(IXY.EQ.4)GO TO 2                                               004010
100   STOP                                                             004020
400   FORMAT(10I3,F10.3)                                                004030
401   FORMAT (8E10.3)                                                   004040
403   FORMAT (4(F6.3,2F7.4))                                            004050
404   FORMAT (15F5.2)                                                   004060
405   FORMAT (8E9.2)                                                    004070
406   FORMAT (7F10.3)                                                   004080
407   FORMAT (//10X,28H HORIZONTAL PATH, ALTITUDE =,F7.3,12H KM, RANGE =004090
     1,F7.3,3H KM)                                                     004100
416   FORMAT (/20X,12H HAZE MODEL ,I1,3H = ,A5,13H VISUAL RANGE)       004110
417   FORMAT (/25X,*HAZE MODEL =*,F5.1,* KM VISUAL RANGE AT SEA LEVEL*)004120
418   FORMAT (/10X,21H FREQUENCY RANGE V1= ,F7.1,13H CM-1 TO V2= ,F7.1,1004130
     14H CM-1 FOR DV =,F6.1,9H CM-1 (,=5.3,* - *,F6.3,* MICRONS )*)    004140
422   FORMAT (1H1,/10X,32H FREQ WAVELENGTH TOTAL  H20,5X4HCO2+,5X,6004150
     14H07ONF  N2 CONT  H20 CONT MOL SCAT AEROSO- AEROSOL INTEGRATED004160
     2 /11X,14H CM-1 MICRONS,5(4X,5HTRANS),4X,20H ABS  ABSORPTION )    004170
423   FORMAT (10X,I6,10F9.4,F12.2)                                      004180
424   FORMAT(/* INTEGRATED ABSORPTION FROM*,I5,* TO*,I5,* CM-1 =*,F10.2,004190
     1*  AVERAGE TRANSMITTANCE=*,F7.5)                                 004200
426   FORMAT (/20X,*AEROSOL SCATTERING NOT COMPUTED,IHAZF=0*)          004210
430   FORMAT(10X,*  INPUT METEOROLOGICAL DATA*/10X,*Z=*,F7.2,*KM, P=*,F7.004220
     12,*MB, T=*,F5.1,*C, DEW PT=*,F5.1,*C, RH=*,F5.1,*%, WH=*,E10.3,*GM004230
     2M-3, VIS RGE=*,F6.1,*KM, RGE=*,F10.3,*KM*)                       004240
431   FORMAT (4(F6.2,2F7.5))                                            004250
442   FORMAT(* FOG CONDITIONS MAY EXIST AT SEA LEVEL FOR THIS VISUAL RA004260
     1NGE*,/,* IF SO THEN ASSUME THE TRANSMITTANCE DUE TO FOG IS GIVEN 004270
     2BY THE TRANSMITTANCE AT 0.55 MICRONS.*)                         004280
443   FORMAT (2F7.3)                                                    004290
```

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444  FORMAT(F5.1,F7.3)                                                       004300
445  FORMAT(/9X,34H AVERAGE WATER VAPOR TRANSMISSION=,F7.5)                   004310
446  FORMAT(9X,34H AVERAGE AEROSOL TRANSMISSION    =,F7.5)                    004320
447  FORMAT(9X,34H AVERAGE MOLECULAR TRANSMISSION  =,F7.5)                    004330
448  FORMAT(9X,26H WATER VAPOR TRANSMISSION=,F7.5)                            004340
     END                                                                     004350
```

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Appendix B

Draft Calibration Handbook

for

Barnes Model 14-WP Transmissometer

As designed, the Barnes transmissometer is expected
to require recalibration at three month intervals. Because
of the difficulty of bringing the receiver and electronics
to the transmitter assembly for calibration, it is desirable
to use the transmission measurements themselves to determine
when recalibration is required. This appendix discusses a
technique for accomplishing this and then provides a step by
step description of the calibration procedure.

Determine When Calibration is Required

The transmission measured by the Barnes Transmisso-
meter can be separated into the transmissions of 3 different
constituents of the atmosphere, the aerosols, the water
vapor, and the remaining molecular absorption.

$$\tau_{Total} = \tau_{Aerosol} \times \tau_{H_2O} \times \tau_{Mol}$$

The aerosol transmission, $\tau_{Aerosol}$, is a function of visi-
bility, VIS. The water vapor transmission, τ_{H_2O}, is primarily
a function of the dew point temperature, T_{Dew}, with a minor
temperature dependence. The transmission by the other
molecular absorbers can be considered a constant with a very
weak temperature dependence. Given a knowledge of the
visibility, dew point temperature, and the air temperature,
it is possible to predict, within a few percent, the expected
values of the transmission for each of the receivers of the
Barnes Transmissometer. Figures B-1 through B-18 permit
making these predictions. Figures B-1 through B-6 are for
the visible receiver, B-7 through B-12 are for the near-IR

receiver and B-13 through B-18 are for the far-IR receiver. The following steps should be accomplished for each spectral band as indicated on the figures.

1.   Using the visibility figure, find the predicted aerosol transmission, $\tau_{aerosol}$.

2.   Using the dew point figure, select the temperature curve closest to the ambient temperature and find the predicted water vapor transmission, τ_{H_2O}.

3.   Using the curve labelled τ_{Mol}, find the predicted molecular transmission.

4.   The expected transmission for the appropriate wavelength is then the product of the three constituent transmissions.

$$\tau_{Expected} = \tau_{Aerosol} (VIS) \times \tau_{H_2O} (T_{Dew}) \times \tau_{Mol} (T)$$

5.   If the measured transmissions are more than 0.1 lower than the expected transmissions for good visibilities (10 to 20 kilometers or better), the Barnes Transmissometer should be recalibrated.

Calibration Procedure

1.   Remove the dust cover from the transmitter assembly

2.   Mount the receiver to be calibrated onto a small rotary table and place the assembly on the telescope bed. CAUTION. Do not bump the spider mirror.

3.   Assure that the receiver optics are looking entirely into the telescope mirror. Use a sheet of white paper in front of the entrance aperture to confirm this.

4. Install the 10X attenuator in connector J2 on the mother board of the electronics unit for the receiver being calibrated.

5. Place the system in normal operation and use the JOG button to select the filter wheel position to the maximum response position as indicated in the manufacturer's calibration data book.

6. Select the 0.1405 inch aperture.

7. Rotate the receiver slowly in azimuth and elevation to produce the highest indication first on the ANALOG ALIGNMENT meter and then on the PERCENT TRANSMISSION digital readout indicator.

8. Lock the position settings on the Receiver Assembly.

9. Set the aperture wheel on the source to the next smaller setting and repeat Steps 4 through 8. Continue to repeat this procedure with smaller and smaller aperture settings until the one marked CAL is in position, then lock the rotary table.

10. On the Receiver, adjust the PHASE CONTROL knob to produce the maximum reading on the ANALOG ALIGNMENT Meter.

11. Observe the indication on the PERCENT TRANSMISSION display. If it is not 37.3, proceed to Step 12.

12. Unlatch the lower right panel in the receiver electronics unit and slide the chassis forward. Locate the calibration screwdriver adjustment at the upper right of the circuit board as seen from the component side. Rotate this

adjustment to produce a reading of 37.3 on the PERCENT
TRANSMISSION digital display. Approach the 37.3 indication
slowly by going up through lower indications and stopping as
soon as 37.3 appears on the display.

At this point, the receiver is calibrated
for the wavelength of maximum signal "Thru-put".
Next, a printer is interfaced to the computer output
connector. At each stopping position (wavelength),
the BCD position is recorded along with the voltage
displayed on the panel meter. The filter drive must
be in AUTO mode. From this printout the factors are
determined which will be used to normalize the data
at each wavelength for a 37.3 reading with no path
attenuation.

13. Recalibrate the other two receivers by using
the same procedure.

14. The Atmospheric Transmissometer System is now
recalibrated and can be placed back into normal use once the
radiation source aperture wheel is returned to its initial
position.

AEROSOL TRANS VS VISIBILITY

H2O TRANSMITTANCE VS DEW POINT
FOR VARIOUS TEMPERATURES

⊙ : TMP = 0
△ : TMP = 20
+ : TMP = 40

⊙ : TMP = 0

filter angle: 99.84°

TRANSMITTANCE
100.00 87.50 75.00 62.50 50.00 37.50 25.00 12.50 0.00

VISIBILITY
0.00 5.00 10.00 15.00 20.00 25.00 30.00 35.00 40.00

DEW POINT
-20.00 -14.00 -8.00 -2.00 4.00 10.00 16.00 22.00 28.00
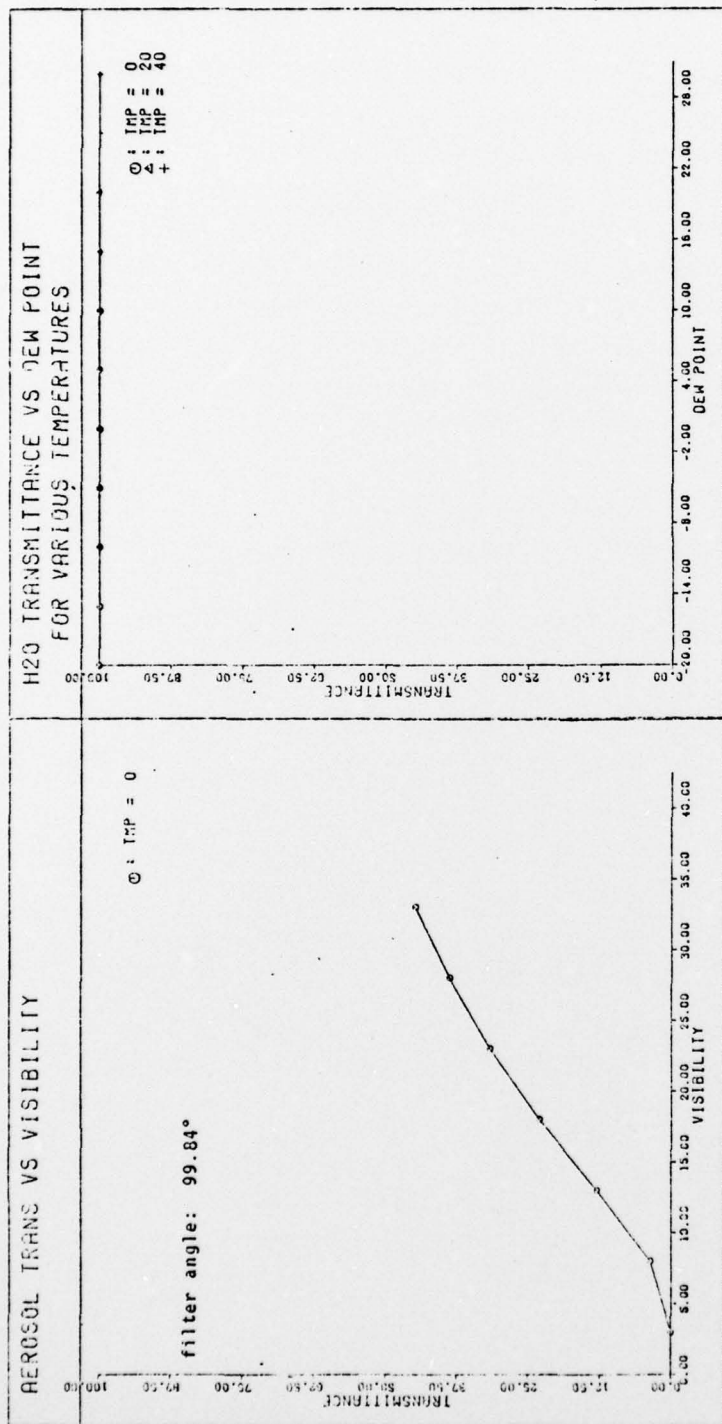
Fig. B1. 0.6 um Transmission as a Function of Visibility and Water Vapor Content

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AEROSOL TRANS VS VISIBILITY

⊖: TMP = 0

filter angle: 215.16°

H2O TRANSMITTANCE VS DEW POINT
FOR VARIOUS TEMPERATURES

⊖: TMP = 0
◁: TMP = 20
+: TMP = 40
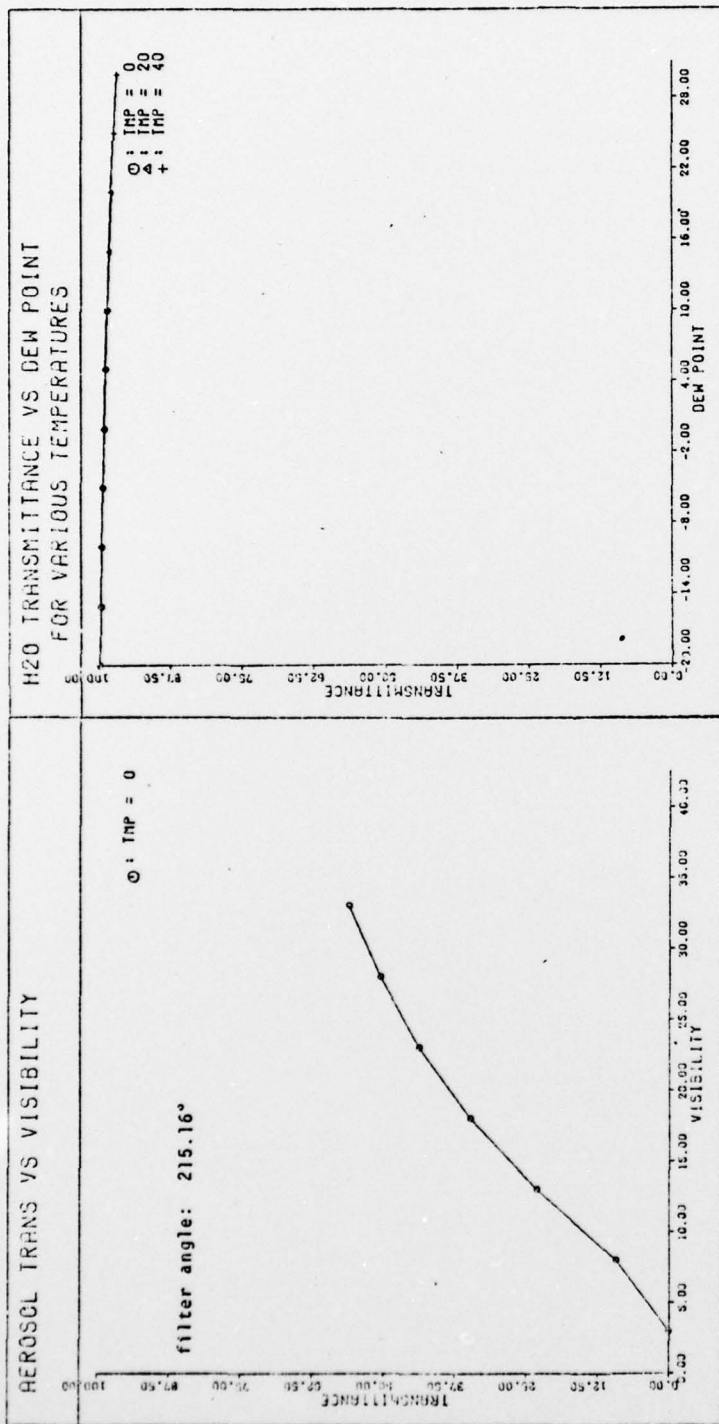
Fig. B2. 0.79 um Transmission as a Function of Visibility and Water Vapor Content
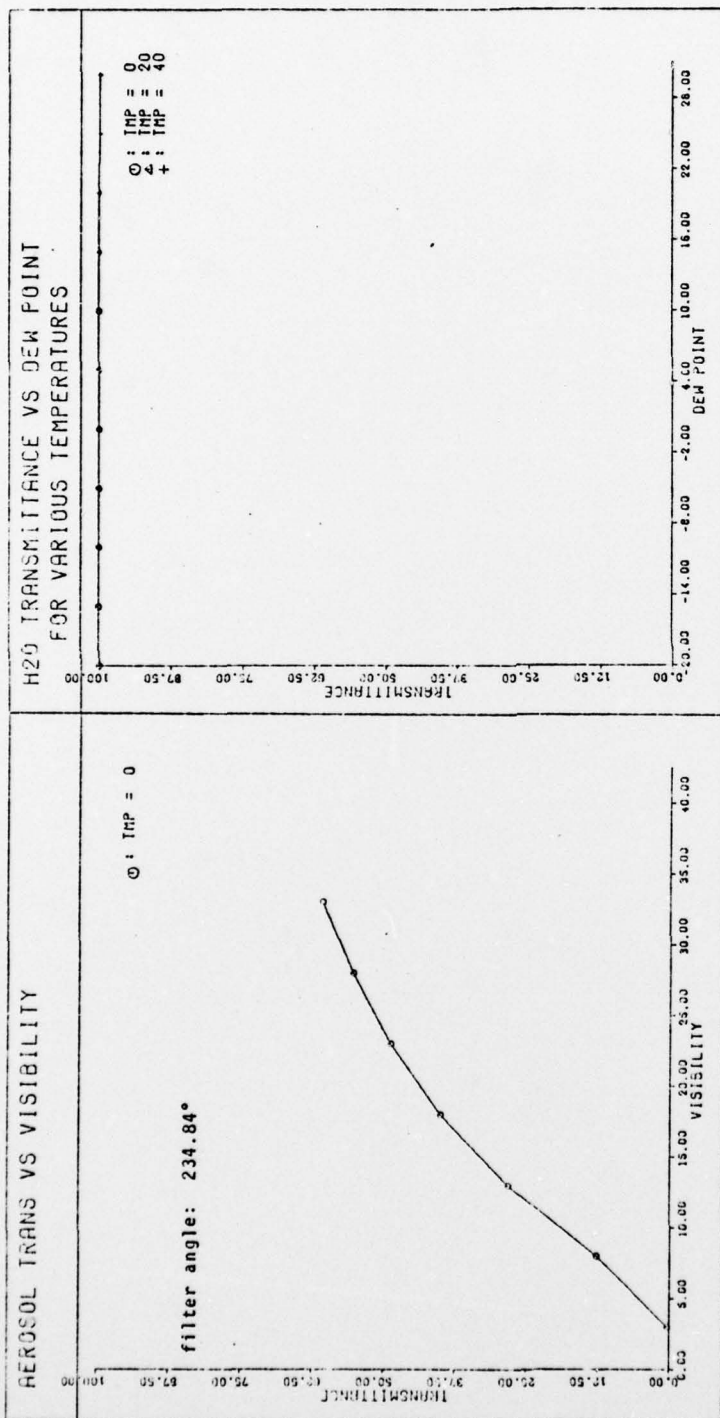
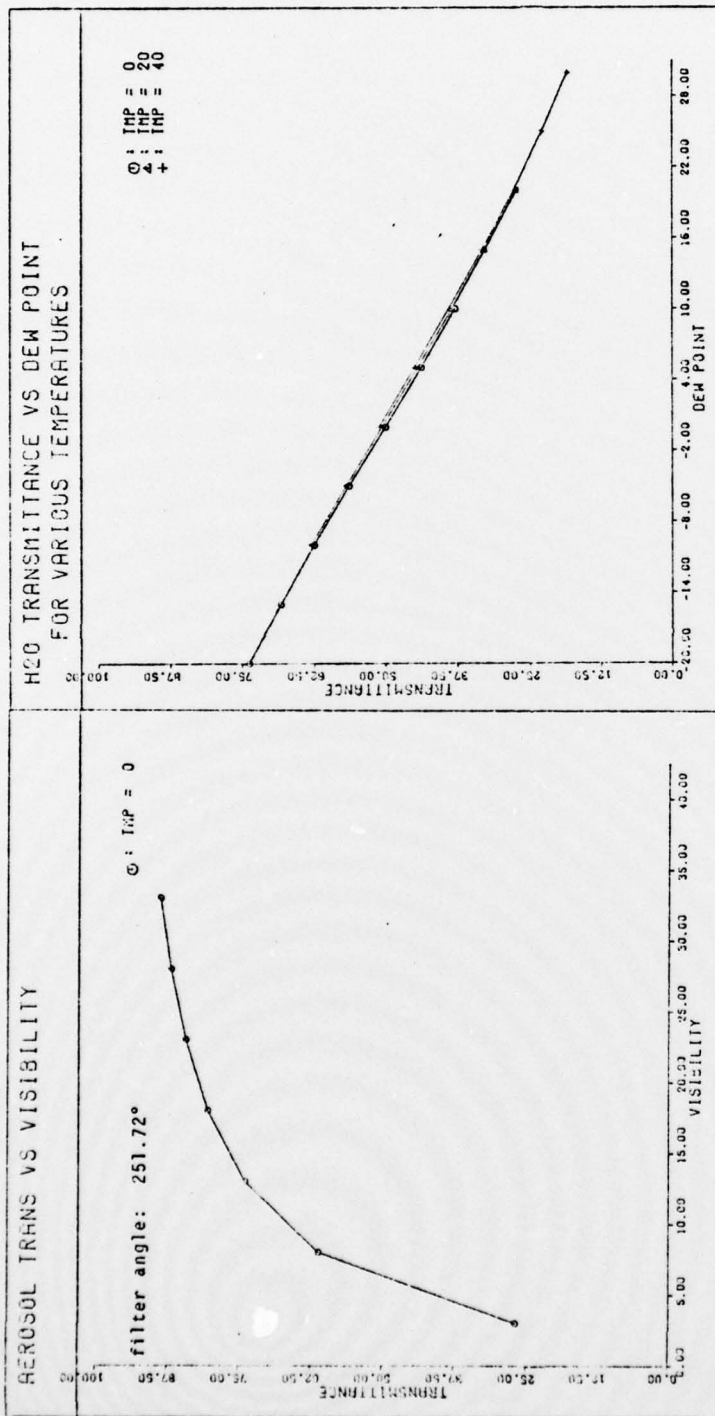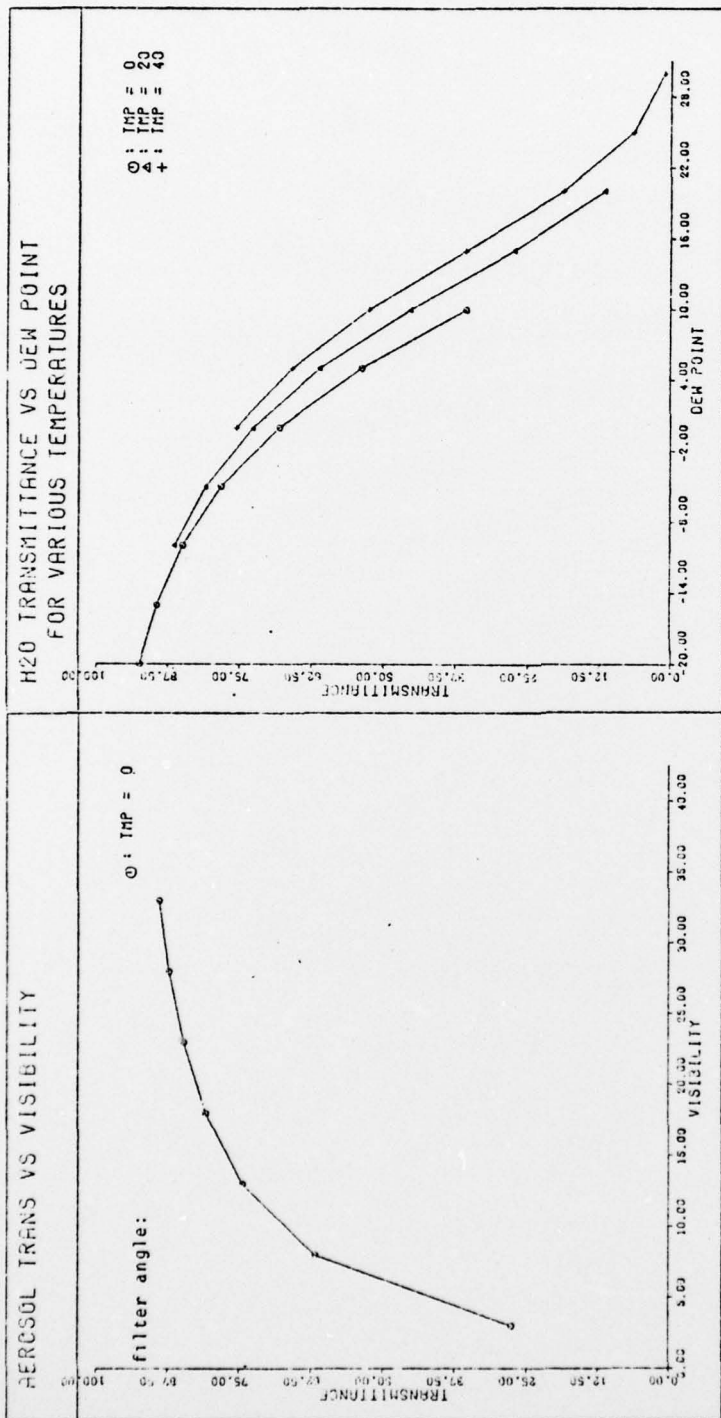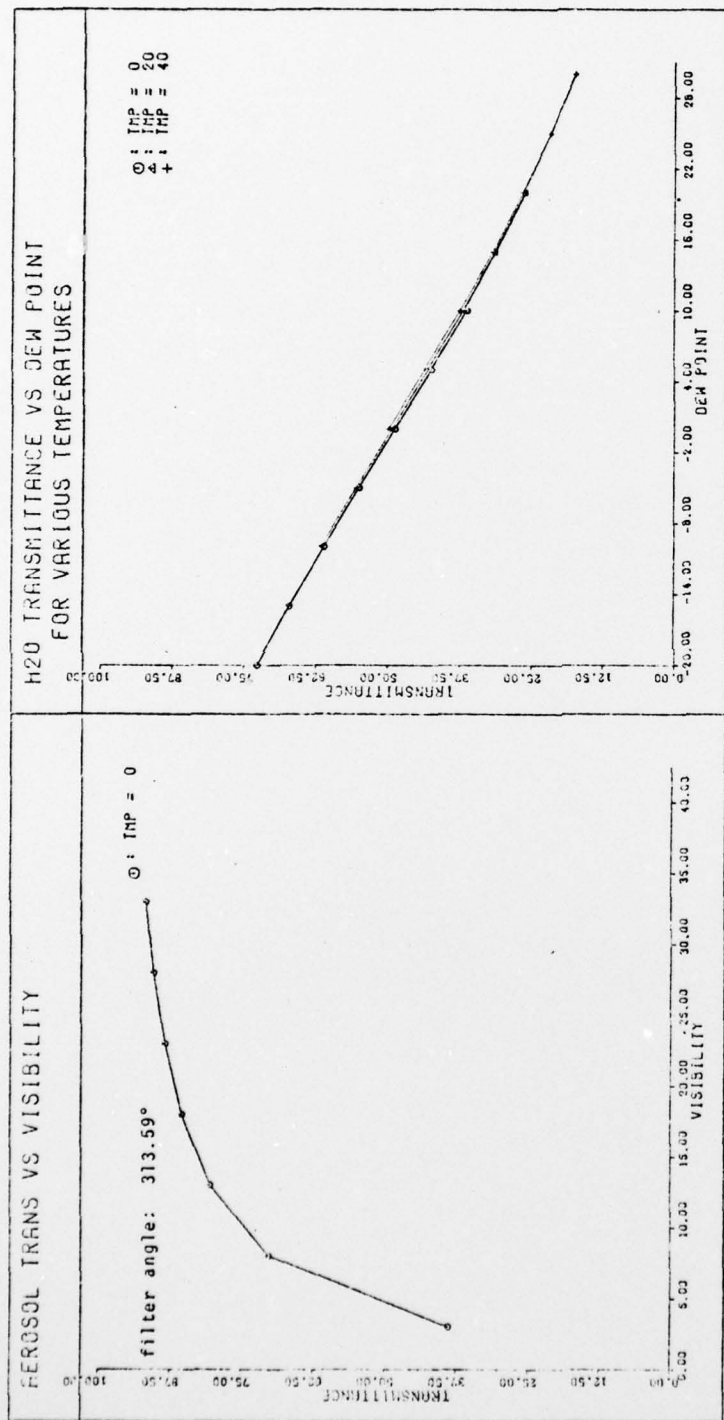Fig. B3. 0.87 um Transmission as a Function of Visibility and Water Vapor Content
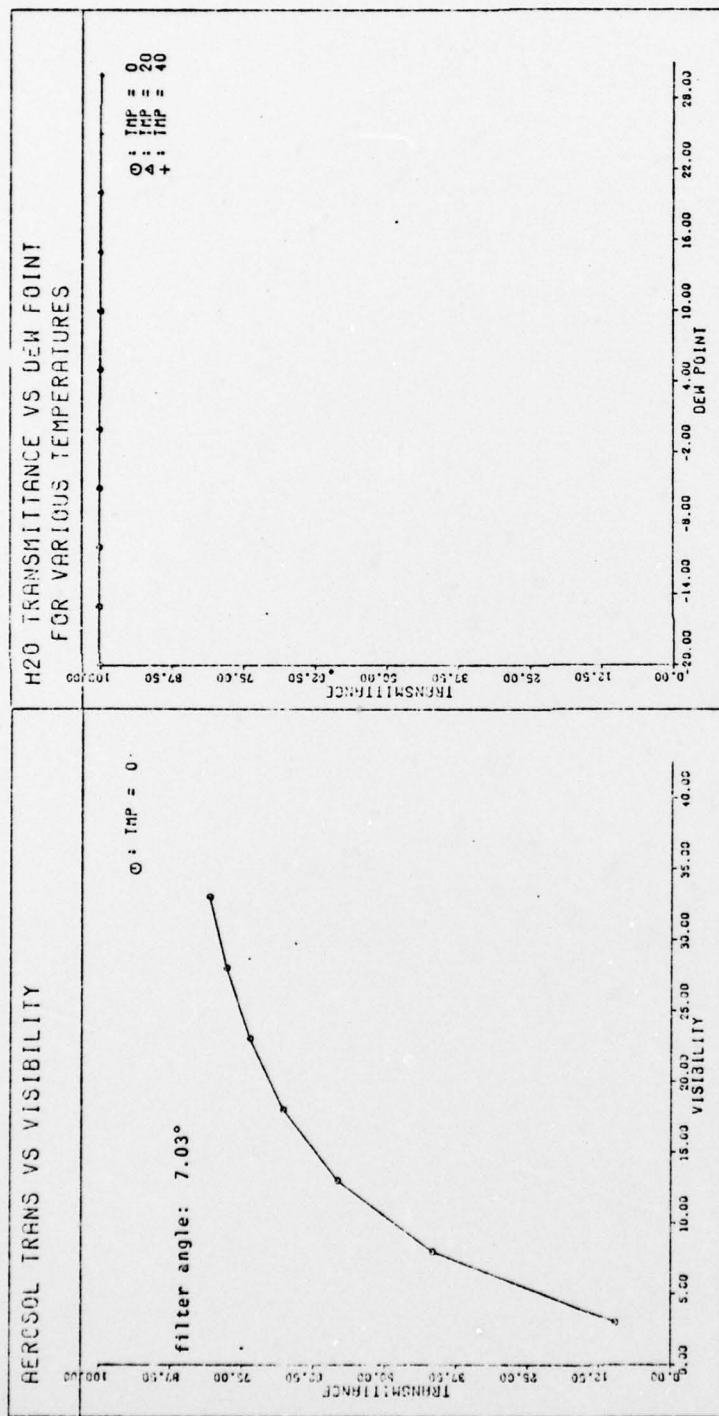
Fig. B4. 1.62 um Transmission as a Function of Visibility and Water Vapor Content
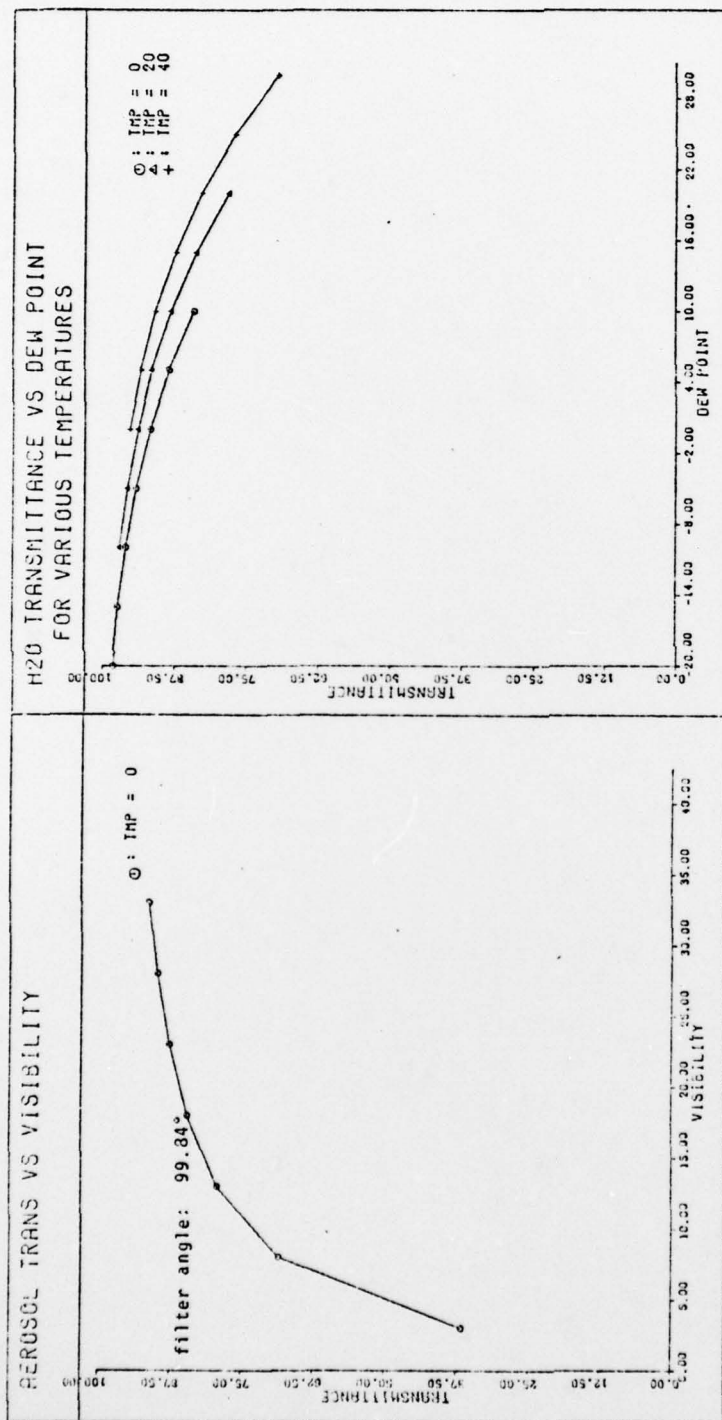
Fig. B5. 2.41 um Transmission as a Function of Visibility and Water Vapor Content

Fig. B6. 3.98 um Transmission as a Function of Visibility and Water Vapor Content

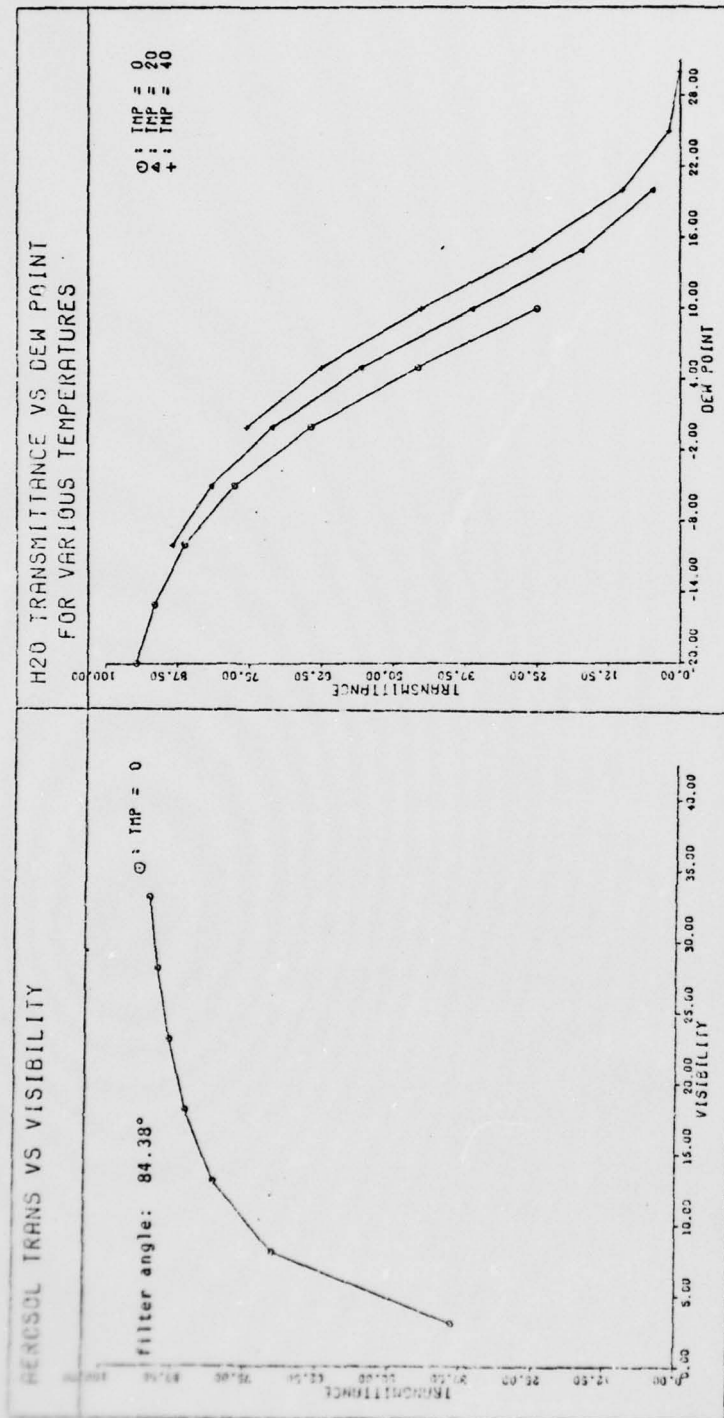Fig. B7. 4.81 um Transmission as a Function of Visibility and Water Vapor Content

AEROSOL TRANS VS VISIBILITY

⊙ : TMP = 0

filter angle: 313.59°

H2O TRANSMITTANCE VS DEW POINT
FOR VARIOUS TEMPERATURES

⊙ : TMP = 0
△ : TMP = 20
+ : TMP = 40

Fig. B8. 9.12 um Transmission as a Function of Visibility and Water Vapor Content

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AEROSOL TRANS VS VISIBILITY

H2O TRANSMITTANCE VS DEW POINT
FOR VARIOUS TEMPERATURES

⊙ : TMP = 0
△ : TMP = 20
+ : TMP = 40

filter angle: 84.38°

⊙ : TMP = 0

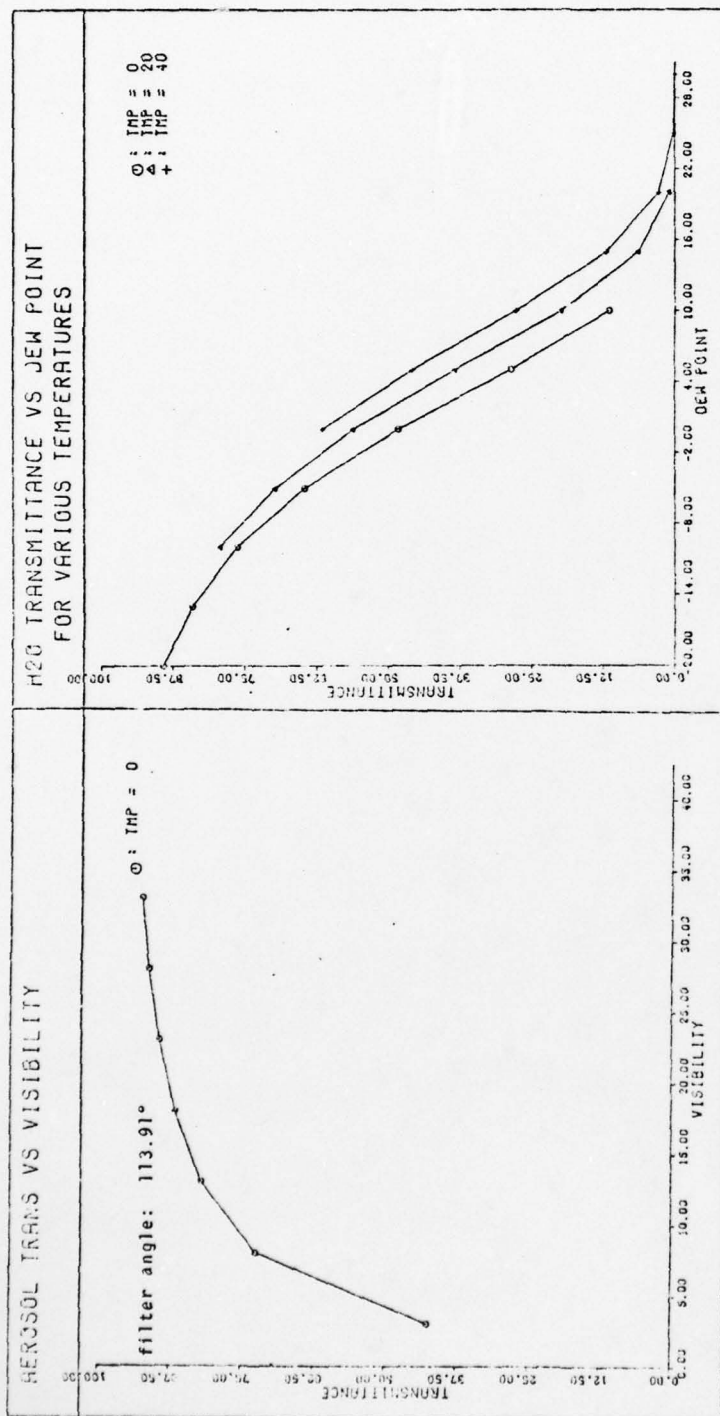Fig. B9. 10.78 um Transmission as a Function of Visibility and Water Vapor Content

Fig. B10. 11.95 um Transmission as a Function of Visibility and Water Vapor Content

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VITA

Leo Owen Vroombout was born 6 September 1940 in
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The Barnes Model 14-WP transmissometer is one of the principle optical path calibration instruments of the Air Force Avionics Laboratory's Targeting Systems Characterization Facility. A simple test based on LOWTRAN IIIB was devised to certify system calibration while installed on an eight kilometer optical path. In addition, an optical path anomaly was investigated. Results are discussed and recommendations for additional calibration tests and new procedures are made.

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